TO ENGINEERING ENTERPRISE

ABROAD

EWING MATHESON

AID BOOK

TO

ENGINEERING ENTERPRISE ABROAD.

PART II.

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ABROAD.

BY EWING MATHESON,

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FAC ET SPERA

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PREFACE.

THE present volume forms a sequel and conclusion to the First Part of the Aid Book published in 1878, which treated of the inception of Public Works and of the various conditions on which the success of engineering enterprises depends. In this Second Part attention is drawn to the various modes of contracting, and to the circumstances which, in each case, determine the design or choice of machinery and material. These particulars are given specially as an aid to foreign or colonial transactions, in which disappointment often arises from want of a full understanding between those concerned.

Suggestions for additions to or improvements of the contents of these volumes will be gratefully received by the Author for use in a future Edition.

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MATHESON'S AID BOOK.

THE Chapters in the present volume are numbered on from those in Part I. to avoid confusion. But although reference is occasionally made from one to the other, the two Parts treat of different subjects, and may be purchased separately. The Contents of Part I. are enumerated at the end of this Volume.

CHAPTER XIV.

CONTRACT AND PURCHASE IN THE ENGINEERING TRADES.

Questions arising out of contracts more complex than in ordinary trades.

THE questions which arise out of contracts for public works, and the various other enterprises which depend upon engineering skill for their achievement, are generally more complex than those connected with the purchase of ordinary commodities. It is intended in the following pages to classify the principal methods in which purchases and contracts are arranged, and, while avoiding purely legal considerations, to draw attention to some of the more important circumstances connected with them, both in regard to transactions completed in the country of purchase and those in which the incidents of export have an important place.

Intention of this Chapter.

Prices arranged in advance.

It is the almost invariable practice to arrange prices and conditions at the commencement; and although there are certain transactions in which exact pre-arrangement is impossible, the leaving of price or remuneration to be settled after completion occurs now much more rarely than formerly. The necessity for such preliminary agreement arises not only from the desire of a purchaser to know how much he will eventually have to pay, but to enable him to choose between two competing sellers, whose offers can only be compared by knowing them at the outset. It is evident that a mere comparison of prices will not alone allow of a fair judgment between them. Competitive prices must either be based on precisely similar conditions, or the purchaser must be aware of the differences, and

Reasons for re-arrangement.

Comparison of prices.

Bargains have three parts: 1. Agreement to sell. 2. Technical conditions. 3. Measure of price.

have some standard by which to judge. For the present purpose it may be said that bargains for the purchase of commodities or the performance of works have three essential parts: the agreement or contract to sell and buy, technical and other conditions, and measure of price. The agreement or contract is sometimes merely verbal, more usually by interchanged letters, and sometimes by formal deed. Technical conditions of the commodity or works are described or implied either by

See page 4.
1. Specification or Description furnished by the Buyer.
See page 11.
2. Specification or Description furnished by the Seller.
See page 15.
3. Sample.
See page 17.
4. Reputation or Trade Mark of the Seller.

The payment or measure of price is either—

See page 20.
a. A Sum of Money.
See page 21.
b. According to Schedule Rates.
See page 28.
c. By Units of Contents.
See page 30.
d. By Results accomplished.
See page 30.
e. By Measure and Value.

Contracts made by letter only.

In regard to the first essential—the agreement to sell and buy—a large proportion of English contracts are made in the most simple manner by the interchange of letters, one letter offering to sell certain goods or to carry out certain works for a specified sum of money or other consideration, and a return letter accepting such offer. Or the method may be reversed, the purchaser making an offer and the seller accepting it. Extensive commerce could not be carried on if every transaction needed an elaborate contract document or the intervention of a lawyer; and the simplicity of the English system compares favourably with the formal and tedious contracts adopted on the Continent more often than in England, and which are apt to repel those unaccustomed to them.

Commerce hindered by elaborate documents.

Formal documents evolved by recurrence.

Formal or legally-drawn documents are usefully applied in the transfer of leading commodities, where transactions of a similar kind continually recur; use and custom having led by a gradual process to the elaboration of forms of contract, or precise clauses, to meet contingencies suggested by past experience. The printed bought-and-sold note of an iron-broker, the charter-party and bill-of-lading of a ship-owner, are instances in point; but in the more frequent transactions, for which there is no exact precedent, such elaboration is wanting, and the essentials being stated, secondary conditions are only implied or

Instances.

understood, leaving to the common law and custom of the land the inferences involved. If such a method of business resulted in vague or ill-defined contracts, it could not be justified, and engineers or others whose duty it is to draw up agreements should, unless they have good precedents to guide them or accumulated experience of their own, be assisted by legal advisers. But those who are accustomed to the commerce of the engineering trades are generally able to put into a binding and explicit form the bargain they have made; and the sufficiency of such forms would appear to be proved by their frequent adoption.

Common law and custom.

Simple methods proved sufficient.

For undertakings of large extent, or which are likely to be protracted, it is endeavoured usually, by great care and consideration at the outset, to avoid after disputes; but in all contracts, large or small, care should be taken to set forth all the essential conditions, to avoid ambiguity, and to make the documents—letters or more formal agreements, as the case may be—explicit and self-contained. But letters make a satisfactory contract only when complete in this simple form, but not so when the terms of agreement are distributed through numerous letters or a protracted correspondence. If at the time of agreement, the usage in previous transactions qualify or extend the apparent meaning of written conditions, such elucidation should, if possible, be added or embodied in writing while all are agreed, or at any rate the words "as customary" be employed. If in previous transactions between the same parties a custom has been established, such a phrase may serve, but if a common "custom of the trade" is meant, then it will be binding only on proof that it is universally adopted and acted on in the trade. Accuracy in stipulations of this kind is especially necessary where the two parties to a contract are not equally informed as to the usage.

Care at outset.

Ambiguity to be avoided.

Or too many letters.

Verbal qualifications.

See also page 17.

The agreement to sell and buy is conveniently kept distinct from the detailed conditions; and just as a short form of tender and still shorter acceptance of it may refer to the most elaborate specification, and also even where, instead of such a simple arrangement, formal contract-deeds bind buyer and seller to a bargain, it is usual and convenient that the specification of technical conditions should be kept distinct. But a contrary custom often prevails, and the general conditions or framework of a contract are mixed up with the descriptive particulars which more properly pertain to a specification. This method prevails oftenest when the conditions are stated according to the first method in the category on page 2.

Agreement separate from specification.

Contrary method.

Specification furnished by buyer may describe purpose or result only.

(1) *A Specification or Description furnished by the Buyer* may be said to imply that the buyer knows what he wants and describes it; leaving the seller no choice but to supply what is so described. A specification may, however, be limited to a description of a purpose in view or results to be obtained, leaving the seller either free scope in the manner of performing it, or necessitating on his part also a specification to show what is intended, and to allow a choice between competing sellers. So far as a buyer specifies his wants, he relieves a seller of responsibility in the choice, unless the contrary be explicitly declared. A specification may consist only of a brief description, or a drawing, or a mere sketch; but, if such be the basis of a contract, it will—so far as it goes—declare where the responsibility rests. If the thing or the service asked for be something new, the seller may be entirely relieved from responsibility if he obey the specification, even though the purpose for which it is intended be incidentally mentioned, and the article supplied or work done fail to fulfil that purpose; but if the purpose be mentioned and no description be given of the method of fulfilling it, the burden will be upon the seller of supplying what is suitable and fit. A buyer sometimes even seeks to combine both arrangements, but improperly so, *i.e.*, to decide himself upon the method and yet to lay the responsibility on the seller. Thus, an engineer may design a bridge, and may make the manufacturer not only responsible for following the drawings and giving materials and workmanship of prescribed kinds, but, in addition, he may stipulate that the bridge shall under a certain test load only bend a specified amount, or that one span of the bridge, if it be tested to destruction, shall break only with a certain load. Or, a steam-engine of certain dimensions may be designed, and a certain working-pressure and speed prescribed, and the manufacturer be called upon to warrant an effective horse-power of a certain amount. A manufacturer who accepts such liability may be bound to it, but in such a case he has pledged not only his ability as a manufacturer, but his skill as an engineer to verify the calculations of the designer. If, without attempting to verify the calculations, he rests content on his belief in the ability of the engineer, and the bridge or engine fail to reach the specified test—not through any defect of manufacture, but because the methods and the result are shown to be irreconcilable—the manufacturer will have to bear the loss; but probably in such a case, the terms in which he contracted would have to be very strictly weighed before such unwisely assumed responsibility could be enforced by a legal tribunal.

Responsibility allotted.

Undue risks imposed on seller.

Instances.

Such liabilities inexpedient.

And of doubtful force.

In a specification of the buyer, it is generally inexpedient to describe the details of workmanship or the methods to be therein pursued, unless on the basis of a full knowledge of the subject; for the mistakes or discrepancies which are likely to result will afford room for disputes and evasions. It is much better in such a case to describe as clearly as possible the ultimate object in view, and in general terms the quality that is desired, thus putting upon the contractor the responsibility of doing what is evidently demanded. The force of such general terms is weakened by adding detailed instructions, unless the the latter be very complete, because their presence in regard to some parts implies that the contractor is to look to the specification for instructions, and that, where absent, no particular methods are desired. But there are cases where the opposite plan is preferable. Thus, there may be some article which can only be tested by long use, and any composition or method of manufacture which has proved best in the past may be prescribed with advantage. The alloy for an engine-shaft bearing, or for pump-barrels, is sometimes specified with much minuteness where seemingly more important parts are left to the manufacturer.

Buyer should not prescribe methods.

But results only.

Opposite plan sometimes expedient.

Instances.

The advantage to the buyer of affording a full knowledge to the seller of what he will be called upon to do under an anticipated contract is so well understood by those experienced in such transactions, that much trouble and expense are frequently bestowed on the calculations beforehand of the scope or extent of a coming undertaking. Buyers do not always recognise what is involved in the omission of such an investigation, or the putting the burden of it on the seller. Particulars presented to manufacturers or contractors upon which to frame their tenders may be insufficient in the sense that they are vague or incomplete, or in another sense, that while full and elaborate, they are so voluminous as to be difficult of computation. As an example of the first kind, if a buyer ask for a steam-engine of a certain power, and omit to state whether it is to include a boiler, or at what pressure it is required to work, or how its power is to be computed; or if a bridge of a certain span be required, and no width of roadway or amount of load be stated, the various prices which different manufacturers under such a specification may offer will of themselves afford no true basis for comparison. Indeed, were it not the case so often that those not technically informed do present a meagre specification, and act upon prices unaccompanied by a specification of the seller, the fallacy of such a method would appear too

Buyer should afford full knowledge of his wants.

Particulars often insufficient.

Instances of vagueness.
See page 49, and in Part I. page 50.

Prices on such basis inconclusive.

For lowest offer may imply low quality.

obvious to be mentioned. For of such prices, the lowest will probably come, not from the manufacturer who will do what is really wanted most cheaply, but from him who has interpreted most lightly the duties involved, or who will venture—in good faith possibly—on the lowest margin of strength and safety in the structure. The knowledge among competitors of this inconclusive method of comparison tends to degrade the quality of commodities. A comparison of offers based on an insufficient specification of the buyer can only then be made by requiring with each price a description of what it is intended to supply; and this method of contract involves certain contingencies which will be presently described under the head of Specification of the Seller. It is very difficult in the case of certain commodities to apply a standard of quality. Thus, in the purchase of iron or chemicals, the real value may be ascertainable only by elaborate tests or analysis, and purchase by sample or by units of contents becomes expedient. And in the opposite case referred to above, the drawings and description of works might be so varied and voluminous as to involve great trouble and expense in calculating the value of what they represent.

Specification from seller then necessary.

See pages 11 and 17.

Particulars varied or voluminous.

Calculation of quantities.

The first step in making an estimate of cost is to reckon up the quantities of material and labour required. In simple matters, each competitor may be left to calculate these items: for instance, in the purchase of a steam-engine or a lathe, there is no need to tell the seller the number and dimensions of the various pieces in the machine, or its weight. And, in regard to larger and more complicated works, the purchaser may deem it best to leave each competitor to calculate in his own way the cost of the undertaking. Indeed, the skill and experience which enables one contractor to estimate, more correctly than another, the cost of works, is a distinct advantage which he may desire to retain; and, if the competition be limited to a few, he may prefer to take the trouble which such calculations involve, rather than have facilities granted to all. But it is questionable if it is to the advantage of the purchaser to limit the competition to the few who are able to calculate the quantities of works, for ability to carry them out may be more widely found. And, if numerous tenders are invited, even experienced contractors may be unwilling to make troublesome estimates where the chance of success is but small. On the other hand, there are certain undertakings in which the cost will depend mainly on the methods pursued, and where there is no difficulty in calculating the quantities. But to

Sometimes left to seller.

Seller may prefer it.

Not advantageous to purchaser.

Contractors may be unwilling to tender.

calculate from drawings and description the quantities of some important work like a railway, a harbour, or a bridge, is often a protracted and expensive operation; and not only is much waste of time and money involved by putting the burden of this on each competitor when it might be done once for all, but there is the probability that the apparently most favourable tender will come, not from the contractor willing to work most cheaply, but from one who has arrived at the lowest measurement. It is customary, therefore, in important undertakings, for the buyer to calculate the quantities and to furnish a list of them to the competitors, so that each may form an estimate on a similar basis. So much does the custom of calculating the quantities beforehand prevail in certain trades, such as the building trades, that a separate profession, that of quantity surveyor, has arisen to satisfy the demand, and "bills of quantities," calculated by able and impartial surveyors, are accepted by buyer and seller alike as a basis of a contract. Quantities so furnished serve as a useful check on the drawings, and allow a buyer to verify, more easily than he otherwise could do, that he has obtained all that he bargained for, for where quantities have not been agreed upon, opportunities for evasion are more frequent. Thus, in the case of a large bridge, or roof, or other structure of iron, it is difficult to measure exactly the thickness of the various parts, and a manufacturer whose price might be two per cent. the lowest, might perhaps supply five per cent. less weight than a skilled surveyor would have calculated from the drawings. A previous agreement on the weight to be supplied removes this risk; and, moreover, the relation of price to quantity affords a convenient standard for measuring the value of additions or omissions. Payments based upon schedule will be presently alluded to. A bill of quantities is particularly necessary when one set of drawings serves for more than one contract, as without such a definition, disputes may arise as to which of two contractors is to execute certain work.

Elaborate quantities.

Reckoned differently.

Unless computed once for all.

Quantity surveyors.

Bills of quantities.

Advantages which they afford.
See also page 22.

See page 21.
In defining extent of contract.

Simplicity in the form of contract is most usual in cases where buyer and seller are equally well informed and come into immediate contact and agreement. The more formal or elaborate contract documents often have the characteristic—in which they differ from almost all other commercial agreements—that they are drawn up entirely on one side, and are not arrived at in the usual way by discussion between the parties concerned, and by that modification of clauses which different points of view suggest. Such a preliminary discus-

Formal contracts often one-sided.

sion being obviously inconvenient and almost impossible in the multifarious cases where contracts for the supply of commodities or the carrying out of works are presented for competition, it would appear desirable for the buyer, instead of looking from one point of view only, as might be justifiable where modification from the other side were to follow, to prepare such equitable conditions as should at once command the confidence of the contractor.

Buyer should offer equitable conditions.

Buyer's obligations not defined.

Even in the best of contracts, drawn up in the interests of a buyer, the obligations of the seller will generally be much more strictly defined than the return obligations of the buyer, who often has duties not confined merely to certain payments of money. Questions which may arise out of these points will have to be decided on inferences drawn from the general tenour of the contract, and such uncertainty, if carried too far, is unsatisfactory to both sides. As instances, a seller may be bound to deliver, but a buyer may not in terms be bound to receive, or to send the inspector whose certificate is preliminary to reception; and being thus unready, may be unwilling to pay. Or, in the carrying out of works, the employer may fail to have the site ready at the proper time or to provide right-of-way to it, and as these obligations are not referred to in the contract, it is by implication only, and as a condition-precedent to be inferred, that a seller can obtain compensation. Certainty and precision are the best bases for a contract, and if those who, unopposed, have the formulating of an agreement, make it one-sided or unduly stringent, it is against the true interests of the buyer for whom they act.

Left to inference only.

Certificates. *See page 23, Part I.*

Certainty and precision best basis for contract.

Price enhanced by uncertainty.

As has just been seen, an exact estimate of cost is only possible where the commodities to be supplied or the services to be rendered can be exactly measured; and if there be doubt as to what may be demanded, an addition is made to the estimate by way of insurance premium against contingencies. In contracts for public works, the engineer frequently takes power to make certain modifications as the work proceeds, or important details are left to be carried out as "the engineer may direct;" but unless this latitude be strictly defined, or corresponding alterations in price arranged, uncertainty will hinder a proper estimate of cost; and the worst of all risks is one depending on the action of another person whose motives are unknown. If, however, it is only intended, and is so expressed, that the contractor may be called upon to obey details which, though propounded after the contract is signed, shall be such as may be reasonably inferred from the contract drawings and specification, such a condition may be accepted

Cost may depend on action of engineer.

Reasonable latitude.

as fair. Uncertainty of this sort may, however, lead to absolute unfairness; for if a favoured contractor had interpreted to him the real intention of clauses (which without such explanation have wide limits), he could measure, more exactly than his competitors, the cost of the undertaking. It is worth much trouble to prescribe everything at the commencement, and where this is impossible, modifications in regard to works or material should be provided for by schedules of rates or prices, so arranged as to allow easy analysis or comparison. Contractors who have much to lose, and who, therefore, are presumably best fitted to carry out a contract, hesitate to engage in one which they cannot measure; or if they venture, they do so only at an enhanced rate. Tenders without such enhancement are made only by those who are ignorant of the risks, and therefore ill-fitted for the work; or by those who are willing to speculate or gamble in unknown risks.

Unfair preference.

Modifications provided for.

Good contractors averse to doubtful risks.

Assuming that the extent of works or services to be performed or commodities to be supplied is so defined as to allow appraisement, there still remains as a point of great importance, the jurisdiction under which the contract is to be carried on or by which possible disputes must be settled. Strong and impartial tribunals, in all countries which possess them, afford great encouragement to commerce, for exact calculation of expenditure and profit can be made only when all risk of confiscation is removed; and the certainty so induced allows, in the competition of traders, a cheapness in price which is to the general advantage of the community. When such confidence is wanting, and where the rights of either side are insecure, public works are neglected and commercial enterprise of all kinds checked. But very often, the insecurity arises even where the laws are just, because by the terms of the agreement some other and outside tribunal is substituted. It is in contracts based on a specification of the buyer that such an evasion of the law is possible, because of the opportunities afforded of making one-sided and inequitable conditions.

Jurisdiction.

See pages 23, 51, 216 Part I.

See page 52, Part I.

Law evaded by one-sided conditions.

Litigation on technical matters is in all countries tedious and expensive, and there has been among trading communities a tendency to provide against litigation by a reference of disputes to arbitration; and the tendency has, in England, been encouraged by the practice of judges to refer cases from their courts, and by direct legislative enactments making arbitration awards binding. Indeed, in some cases, the habit of the judges to refer cases to arbitration has out-

Litigation.

Arbitration.

Favoured by the courts.

stripped public opinion, and litigants desiring the decision of a judge and jury, have been thrust back on a tribunal little or no less tedious and expensive, and whose decisions are less authoritative as precedents. The appointment of an able or impartial arbitrator is obviously a matter of the first importance, and if he be not named in the contract, it is usual to specify the method of choosing one. Among architects and builders in London, the necessity for conditions fair to both sides led even to the drawing up of a set form of agreement, which is frequently adopted as a basis for contracts; the conditions of the building trades in London, the relation of client, architect, and builder peculiar to England, and the general similarity of the undertakings in question, having rendered such a standard form possible. Some such method would be preferable to the custom which too often prevails of appointing, as a condition of the contract, the buyer's engineer as arbitrator without appeal, a practice evidently inequitable though, possibly, convenient.

Choice of arbitrator.

Standard form of arbitration.

Buyer's engineer as arbitrator.

Origin of this stipulation.

Engineers who have the conduct of important works, and who, perhaps, have had unpleasant experience of past disputes, demand such a condition, because it gives them full power over a contractor; and it is because the engineers who have inaugurated this system are men of eminence and position, into whose power contractors have been willing to place themselves, that so bold an innovation has prevailed at all. But such a condition is obviously unfair, for points in dispute are likely to arise from some act of the engineer himself, who is thus made judge in his own cause. Moreover, an engineer may make mistakes causing expense, and it is inequitable to give power to the engineer to save his client from loss and himself from blame by putting the burden on the contractor. The courts scan very rigidly such powers given to an engineer, and when constrained to enforce them, characterise them as unfair, and reprobate strongly the pressure put upon contractors to induce them to contract away their common-law rights. Much indirect harm has been wrought by the establishment of such a custom, for it has been adopted by engineers not entitled to the confidence and consideration given to those who inaugurated it. The inequity culminates when such powers are claimed and made a condition of contract by engineers who have not the independent position which might in rare cases justify such power.

Which is unfair.

Engineer judge in his own cause.

Reprobated by the courts.

Arbitrator not independent.

The desirability of encouraging contractors to compete whom such risks repel, and the obvious advantage of giving that confidence and

certainty of justice which best induces low prices, and in deference also to the expressed opinions of the judges, this custom has been abandoned by most State departments, and equitable arbitration conditions are provided.

This system abandoned by State departments.

(2) *The Specification of the Seller* is made the basis of a contract most often when the commodity sold is one of an accustomed kind, or is a specialty of the seller, or is one in which, for these or other reasons, he is independent of outside skill in design. The use of this method of contract does not, however, entirely depend on such considerations, but in England arises from various other causes. The functions of the professional engineer are kept more distinct from those of the manufacturer or contractor in respect of some branches than of others; and while, in railways, harbours, and the works arising out of such undertakings, the civil engineer generally presents a complete design to the contractor, in other and more purely mechanical works a specification of the seller is invited. Thus while, on the one hand, for works involving operations with land, docks, bridges, buildings, the making of the design is a separate function, on the other hand, the designing of steam-engines and machines is generally left to the manufacturer. The habit of specifying only the purpose in view or the result to be achieved, and inviting the manufacturer to propose his own method of doing it, prevails more frequently in the United States than in England. In America there is not the same line of demarcation between the professional and manufacturing engineer, and no etiquette forbids the combination of the highest skill in public works with the commercial enterprise of the trader. Thus, an engineer-contractor will propose his own method of constructing or improving a harbour, of making a railway, or supplying a town with water, and the condition that payment shall depend on success induces confidence in the offer; or a railway company requiring a bridge may furnish to numerous manufacturers certain particulars in regard to site, span, rolling load, and limit of strain; or, in the case of a locomotive, the load to be hauled, the gradients, and other essential particulars; and then each manufacturer is invited to submit with his tender his plan or specification. This method, while implying considerable enterprise on the part of the manufacturer, and his willingness to incur preliminary expense with a view to after profit, has the great advantage to the purchaser of eliciting the ideas of numerous designers. Moreover, it allows

Contracts based on specification of the seller.

Reasons for this method.

Design left to manufacturer.

Prevails more in the United States.

Engineer-contractor.

Payment depending on success.

Instances.

Advantage to purchaser.

economy in execution, because manufacturers are encouraged to employ the highest engineering skill, and being thus allowed to work in their own way, can venture on special tools or preparations, or can keep suitable material and even finished parts in stock; while where, by the custom of the trade, every buyer presents some new idea or design for execution, no such preliminary saving can be effected.

Promotes cheapness.

Skill needed to compare offers.

But though it may appear easier to the buyer to appreciate and criticise the designs of the seller than to originate similar designs, skill and discrimination are needed to measure and compare the respective merits of numerous offers propounded according to different specifications, which depend upon technical details. Frequently the terms of such specifications afford an insufficient basis of comparison, and the decision has to be guided by the apparent or known ability of the various competitors, or by their conduct in previous affairs. In so far as such considerations prevail, they bring the transactions into the category, presently to be described, of purchases based on the reputation of the seller. The skill which may be required to distinguish between competing offers may also have to be applied to the inspection of the work during or after execution; for though the specification may be that of the seller, the due fulfilment of it has as much to be insured as though the conditions had originated with the buyer.

Difficulties.

Choice guided by reputation of seller.

See page 17.

Manufacturers averse to giving information.

See also page 14.

The specification of a seller often affords valuable information, especially if the description includes drawings or designs; and the best manufacturers are often averse to supplying such information, except when assured of fair play. Where it is intended by the purchaser or his agent to buy from a particular seller, and other offers are asked for, either to give the semblance of competition or to elicit prices, which can then be offered to the favoured seller, such a course of action is uncandid and unfair. In some cases the estimate or tender of an experienced contractor is, as an assurance that certain works can be performed for a specified sum, of as great value to a purchaser or rival contractor as a design or any other essential part of an undertaking. And when the purpose is to elicit not only prices, but technical information and designs, with no intention of paying for them or purchasing the things or works they represent, the transaction is very much like one of obtaining value by false pretences.

An estimate of cost often valuable.

Designs unfairly obtained.

Specification of seller one-sided.

The specification of a seller is often as one-sided as that of a purchaser, for, like it, it is drawn up in the interests of only one of

the parties concerned. All the merits of the article in question are probably set forth, but suggestions which will enable the purchaser to see the demerits and to choose what is better or more suitable are too seldom given. The specification of a seller is sometimes that given in a printed catalogue or price-list, where it may consist only of a brief description or even of a mere picture. But even though the specification be of this meagre kind, the seller is not relieved from responsibility. The article sold must be reasonably fit for its specified purpose. More than this: where a manufacturer, or dealer, or contractor, agrees to supply an article which he is accustomed to manufacture or sell, to be applied to a particular purpose described to him by the buyer, who thereby trusts to the seller's skill and judgment, it may be reasonably inferred that the article sold must be fit and suitable for the purpose in view; and the responsibility for such fitness will rest with the seller.

And deficient.

Seller's responsibility.

How inferred.

Purchasers are greatly assisted by catalogues of manufacturers or merchants, and indeed, the commerce of certain trades could not be carried on without them, especially in foreign countries, where purchasers have no other immediate access to the seller. Although, in the case of important commodities, the catalogue of a manufacturer may be preferred, there are some trades in which the interposition of a factor is almost essential. Thus, in the case of hardware, tools, and other minor articles, the actual manufacture is so divided as to render most tedious the collection of each article from the separate maker by a purchaser, who finds he can obtain what he desires better and more cheaply from a factor of repute, accustomed to the trades in question. Sometimes the intervention of an engineer, technically acquainted with the articles required, is necessary to select or verify the purchases. For the catalogue system is greatly abused, and there are some so-called manufacturers whose stock-in-trade is nothing but a catalogue, and who tempt purchasers by offering inferior goods at apparently low prices. The engravings may be well executed, and there may be nothing by which a purchaser or merchant can detect the truth, for the qualities which really determine the comparative value of two articles apparently similar are not easily discernible by the uninitiated, to whom it may appear a mere waste of money to pay the higher price. The suitability of the design, the proportion of the parts, the quality of material, and the accuracy of the workmanship, determine the fitness and durability of a machine for the desired purpose.

Trade catalogues useful.

Factors.

Aid of engineer to select or verify.

Abuse of catalogues.

Choice from catalogues difficult.

Catalogues impossible in certain trades. But while, in the case of machines, apparatus, or material, which are of an accustomed kind, and which may be enumerated in a list, catalogues are easily compiled, there are, on the other hand, many—and among them the most important—of the trades connected with engineering, where precise catalogues are impossible because of the ever-varying nature of the commodities manufactured. **Instances.** Thus there are factories where steam-engines, mill machinery, or hydraulic apparatus are made, and in which every case as it arises differs from all that have gone before it. So also in the case of structural iron-work, manufacturers of ships, bridges, and roofs find it almost impossible to compile a price-list, because the same combination of dimensions or conditions never repeat themselves, and structures must be contrived to meet each case. **Some makers averse to catalogues.** Many manufacturers of repute are for other reasons averse to printing catalogues. They stand upon their reputation, and are unwilling to publish drawings and prices which will be compared with those of rival or inferior manufacturers, by persons who are unable to discriminate between them, or who may use the information to the disadvantage of the seller. *See also page 12.* But in both the cases mentioned above—namely, in that where, from the nature of the goods, catalogues are impossible; and in the latter, where disinclination rather than difficulty is the cause—much might be done to meet the convenience of purchasers and at the same time promote the interests of the seller. **Other aids to purchase.** Many a profitable piece of business is hampered or gets into wrong hands, because the purchaser has nothing to assist his choice, and does not know where to look for guidance. If, therefore, manufacturers who are unable or unwilling to publish catalogues could give directions to purchasers how to approach them, they would by that alone confer a great service. They need not furnish drawings, they need not even give an inkling of prices, nor describe their goods, but they could inform a would-be purchaser what particulars he must furnish to allow a proper choice, what conditions of purpose or durability will determine price; and, in fact, explain what preliminary steps are necessary to enable those who wish to buy, but who are ignorant, to approach those who wish to sell and are well-informed. **Seller may assist choice.** The position and probable knowledge of the purchaser should guide the seller in the information he supplies. **Preliminary trouble asked or offered.** But in regard to particulars of this kind, and indeed generally to specifications from the seller, the condition of trade at the particular time does much to determine the willingness of manufacturers or contractors to afford information; and while, on the one hand,

traders may, in prosperous or busy times, decline with too much independence all preliminary trouble, so, on the other hand, purchasers are apt to take advantage of dull times to demand from traders the gratuitous supply of designs, prices, and preliminary information of great value.

According to briskness of trade.

(3) *Sample* is not only frequently made the basis of a contract to purchase, but occasionally also of contracts for the carrying out of works. Sometimes the sample is provided by the purchaser, who offers thus a common standard for all competitors, while sometimes each separate offer is based on a sample of its own; these two methods bearing the same relation to each other as the specification of the buyer and that of the seller already described. The purchaser, by allowing the sellers to furnish their own samples, has a wider choice than if a fixed standard was prescribed, and presumably, at the lower prices which a manufacturer or dealer will offer for an accustomed design. If the object of the purchaser be to obtain a choice of numerous kinds, the system of separate samples may be preferable; but if the latitude is merely to elicit low prices from manufacturers, it will generally be found effective only for contracts of small amount; for in large contracts which will repay the cost of special preparations, manufacturers will generally be ready to work as cheaply to a sample of the buyer as to their own. For instance, on a railway of considerable extent, an engineer will generally demand exact conformity to a standard sample for the smallest detail of equipment; while if material only for one mile of railway be required, the engineer's choice of design might well be guided by what manufacturers had ready-made, or could most readily supply. But in any case cheapness is promoted by conformity to accustomed systems of measurement and price.

Purchase based on sample.

Buyer or seller provide sample.

Sellers' samples afford wide choice and low prices.

New samples cheaply worked to for large quantities.

See also page 24.

It is often easier or more convenient to specify various qualities of a commodity by sample than by a written description; and this is especially the case where exact uniformity with something that has gone before is required. Such uniformity may be in colour, form, dimension, or other quality; and may in any of these respects, demand resemblance so exact as to render the old and new interchangeable. Thus, there may be parts of a machine or apparatus constantly wearing out, where the new must fit with accuracy the place of the old; or, as in the case of ammunition, where conformity in a new supply to established standards may be absolutely essential. Or, as in the case of railway equipment, where the material of the permanent-way,

Certain qualities best specified by sample.

Where exact conformity is needed.

or certain parts of the rolling stock, must be similar in kind and size throughout, the standard presented for imitation being considered rather as a pattern than as a sample; other qualities than those of form and size being declared by a written specification.

As in railway equipment.

Comparison by test or assay. *See also page 29.*

A comparison of the bulk with a sample often involves tests, assay, or analysis; and where examination in this way is likely to be resorted to, a preliminary agreement as to the various qualities of the sample should be made between buyer and seller, so that the sample itself need not be examined to afford a basis for comparison in these respects, but may remain to serve as a pattern for form, dimension, colour, or workmanship. In some cases, such as that of wrought-iron, tests by bending may be specified, and the sample serve to show the amount of bending or distortion to be undergone, while other tests for strength and elasticity may be described in writing. In some cases, absolute conformity to a sample is not demanded, but within certain limits, latitude is permitted and allowed for in the price. Contracts so arranged may then come within the category of Purchase by Schedule, or by Units of Contents, which will presently be described.

Specification and sample combined. *See* ROLLED IRON, *Chap. XVIII.*

See pages 21 and 28.

Sample as basis for large works.

Sample is occasional made the basis of contract for the carrying out of large works. For instance, in the extension of a railway, the line or direction and the levels having been agreed upon, the kind of material, solidity of works, and the amount and quality of equipment are summarily specified as to be equal to those of the existing railway, or of a neighbouring line. So also, in the case of a new gas-lighting undertaking, the contract may briefly enumerate the area to be covered and the number of lamps, and in all else refer to the works of some other town as the standard of quality to be followed. Contracts of this kind may, by their very simplicity, avoid occasions for dispute; but, on the other hand, unless the circumstances be exactly similar to those of the prescribed standard, abundant opportunities for difference will arise for litigious persons. Such a method of contract is most suitable between persons who know each other, who by reason of previous transactions attach the same meaning to words, and above all, who have the intention, mutually appreciated, to carry out the undertaking equitably.

As in a railway.

Or in gas-works. *See Chap. XI., Part I.*

Where applicable.

Comparison of bulk with sample. *See also page 29.*

A buyer by sample is not considered to have accepted goods till he has had a reasonable opportunity for examining and comparing them. If goods be found to contain defects, and it be discovered on examination that the sample has hidden defects of a similar kind un-

known to both sides, the seller cannot plead this as a justification for what he has supplied. On the other hand, a buyer cannot claim to have bought by sample merely because, during the negociations, the seller has exhibited specimens of his wares, and given certain assurances. The law is very strict in requiring evidence of warranty, and without touching here upon legal questions, it may be said that where any order is given in writing, it supersedes all verbal communications that have gone before; and the terms of such written order, rather than of any assurances which preceded or accompanied it, will be considered as the contract. Therefore, if specimens or samples have formed part of the preliminary discussion, and conformity to them is required, such a condition must be clearly set forth in the agreement to purchase, and not be left to inference only. The purpose of the sample in regard to which of its qualities—material, dimensions, or other—conformity is required, should be specified.

Hidden defects.

Warranty.

Written contract supersedes verbal assurances. *See page* 3.

Purpose of sample must be specified.

(4) The *Reputation* of a manufacturer, contractor, or dealer may induce such confidence in his ability and fairness, as not only to render the competition of other traders unnecessary, but also to obviate the necessity for a specification of quality. Buyers who have had previous satisfactory dealings with a seller, will continue to purchase from him, and a large proportion of the trade of the country is conducted in this way. The nature of the contract, its quantity or extent, and the real purpose desired by the purchaser having been sufficiently described, the quality of material or workmanship is considered to be sufficiently assured without the minute enumeration in detail of the methods to be followed, or other conditions which generally accompany a specification of the buyer. Or, the seller is invited himself to describe what he will do, and to propose the conditions under which he will work; contracts arranged in this way coming within the category just described, of those based on the specification of the seller. Or, in other cases, the description of kind or quality may be summed up, by the buyer referring to something previously done by the seller, thus in effect basing the contract upon sample and reputation combined. An established reputation is valuable to purchasers who, being concerned more for the proper carrying out of their wishes than for buying on the cheapest terms, buy where they think they will have the least risk; and especially may this be prudent, when business is transacted from a foreign country. It is considered that the trouble of seeking for competi-

Reputation of the seller the guarantee of quality.

This method often adopted.

Specification avoided.

Seller's condition.

Sometimes also with sample.

Buying from abroad. *See Chap. XV.* EXPORT.

tive prices, and the inspecting the work before payment, will more than outweigh the saving in cost that might be obtained. On the other hand, where an existing organisation of engineers, agents, or others is available, advantage may be taken of it to obtain a wider choice; and this is sometimes desirable, not merely for the sake of possible cheapness, but because novel or improved methods and kinds may have arisen.

Wider choice sometimes preferable.

Trade-mark or brand.

The reputation of a maker or dealer is frequently embodied or expressed in a trade-mark or brand, this plan being useful or necessary where the commodities are of a kind which reach the ultimate purchaser or consumer through an intermediary; some mark or sign actually pertaining to the commodity, being necessary as an assurance of its origin. The trade-mark is often convenient as expressing the quality of material to be used by the intermediary in some finished article; as, for instance, where an iron bridge or boiler has to be made of certain plates, the trade-mark on each plate will afford lasting evidence, even after the plates have been manipulated and fashioned into the bridge or boiler, which would be wanting if cast-iron or brass, not so easy to be branded, were the material in question. Trade-marks are used sometimes to denote the origin of, or property in, certain secret or empirical mixtures which have a supposed value. Thus, there may be a peculiar kind of paint or metal alloy, concerning which an inventor or dealer may wish to associate some name or mark that will identify it as his own monopoly. Or, when placed upon some apparatus or machine whose nature or construction is evident, a trade-mark may give a more permanent monopoly to the maker or dealer than would a patent-right limited to a term of years, because while, after the term expires, the right of manufacture becomes common, the monopoly of the trade-mark will remain. But obviously its value will continue, only so long as the seller can induce the belief that his mark or guarantee is the true test of quality, rather than the form or appearance of similarity which may be given by others.

An assurance of origin.

As in the branding of iron.

See ROLLED IRON, *Chap. XVIII.*

Trade-marks of secret mixtures.

Trade-mark more permanent than patent-right.

Trade-marks valuable in distant countries.

Trade-marks have their highest value to purchasers in distant countries; and, indeed, some trade-marks which are of importance there, are hardly known at all in the country of manufacture. Rolled iron, galvanized sheets, and steel tools are among the most familiar examples connected with the engineering trades. To the ordinary purchaser, and indeed often even to experts, there is little in the outward appearance to denote quality; and the trade-mark gives an

Instances.

assurance not only of quality, but of kind also, so that, even in places remote from the port of arrival, the purchaser may know by reference to the trade-mark, that he is getting what he asked for. In the case of certain commodities, such as tools or agricultural implements, the name of the maker is the best of all trade-marks, and if, with the name or appellation, a purchaser states the size or number, so as to identify what he requires, the specification is complete. **Renders purchase easy.**

An established trade-mark, while conferring rights on its possessor, involves obligations which justify the protection which the law affords it. The identity of origin which a trade-mark conveys, is a pledge of quality given by the seller, whose reputation would suffer by any default; and so well is this understood, that the proprietor of a trade-mark will generally take care to maintain the quality, even if circumstances induce him to sell at a low price. But where cheapness is demanded, the proprietor of a trade-mark will try to meet the case by selling goods "unmarked," *i.e.*, without the trade-mark; but if the trade-mark be insisted on, then, whatever the price, the quality which repute associates with it will be given. Sometimes a manufacturer will have various trade-marks, to denote different kinds or qualities. **Trade-marks impose obligations.** **Pledge of quality.** **Unmarked goods.** **One maker having various marks.**

Trade-marks do not always belong to a manufacturer, but sometimes to a dealer or merchant, who, buying where he pleases, gives his stamp or guarantee of quality. A trade-mark or brand may, in such circumstances, merely imply "imported by" or "examined by" the owner of the mark; but the buyer is careless of the actual origin of the goods, if it has been proved by experience and expressed in an established reputation, that a certain kind or quality will be found associated with the mark. This kind of trade-mark may be compared to the resale of goods after an auction, where a would-be purchaser, having no confidence in his own knowledge of the goods offered, and who, therefore, abstains from bidding, may be willing to offer an advanced price to a well-informed bidder, whose bids, if honestly given, may be considered a guarantee of value. **Trade-marks of dealers not makers.** **Why valuable.**

The system of trade-mark or brand is liable to be abused. The actual falsification of such marks, or the fraudulently placing under cover of real marks, inferior goods, are risks which have been greatly lessened by the international treaties which protect trade-marks in foreign countries. But sometimes a trade-mark, implying really no special quality, may, by persistent assertion, attain a reputation undeservedly high among buyers. Or, in other cases, where the mark really implies all that is supposed, a buyer at a **Abuse of trade-marks.**

Insistance on one brand enhances price.

distance may unnecessarily enhance the price he has to pay, by insisting on one particular brand, while a qualified agent, with some latitude allowed him, might choose between several brands equally good, or by his own knowledge, venture safely to buy unmarked goods.

Instance.

This course may, for instance, be rendered expedient when there has been a general fall in the price of some commodity which has not been followed by the goods of a certain brand, and which, therefore, may remain at a price above their relative value.

Some buyers avoid branded goods.

Able engineers often pointedly abstain from specifying trade-marks, and, by insisting only on a prescribed quality, obtain the benefit of an unrestricted competition.

Conventional or common marks.

In some trades, certain conventional marks which have no real meaning, and which are common to all who choose to employ them, are used, this chiefly occurring in the class of goods exported to ignorant or half-civilized peoples.

Referring to the various modes of payment and measures of price enumerated on page 2.

A sum of money the measure of price.

(*a*) *A Sum of Money* is the most usual and simple measure of price for goods to be supplied or work to be done. The price of a commodity that can be clearly defined—a steam-engine, for instance, or a plot of land—is naturally expressed so, and there is no need of any other method; and it is only when the peculiar nature of the contract renders this method inconvenient, that the consideration or payment is stated in some other way.

This method sometimes inconvenient.

To the purchaser, at any rate, a foreknowledge of the exact sum to be paid is convenient; and it is generally the aim in all kinds of contracts, whatever may be the precise way of arriving at it, to agree as nearly as possible at the price.

Foreknowledge of price obtained.

So much do purchasers generally desire this precision, that even in complicated transactions, where it is difficult to appraise beforehand the costs and charges, a price stated in one sum is preferred, because it may be supposed to save all risk of extra charges, even though some other measure would appear to allow a lower and fairer valuation.

Price cheapened if risk removed.

A seller or contractor who is asked to tender for goods or works which, from their quantity, kind, or extent cannot easily be measured in advance, will, on the other hand, offer cheaply only if he is allowed to stipulate for extra payments should certain events arise.

Uncertainty enhances price.

If, however, only offers at a fixed price will be entertained by the purchaser, then an addition is made to the price to provide for contingencies—in effect, a premium of insurance against risks. The advantages however of knowing from the beginning what is to be

paid, often fully justify such a course. As the removal of uncertainty allows a close estimate of cost, contract by a fixed price is facilitated when, by a preliminary calculation of quantity, the extent and nature of the contract is ascertained; and, as has been seen, this investigation is sometimes performed by the buyer and sometimes by the seller. Even with this assistance, the responsibility undertaken by a contractor sometimes involves considerable risk. Thus, the supply of goods or the carrying out of works may be spread over a long period of time, within which there may be great fluctuations in the price of labour and of material, which cannot be altogether met by preliminary agreements or purchases on the part of the contractor. For instance, in railway works, some special cause may drain the neighbourhood of workmen or make labour scarce and dear; or the material to be excavated may prove to be much more difficult than was anticipated. More than this, contractors are sometimes required to include what is not properly within their province, such as the cost of land, the compensation for damage to occupiers, or even the raising of capital on shares. There is the disadvantage to the purchaser, when this system is adopted, that while the contractor reaps all the profit if circumstances prove easier than was anticipated, on the other hand, the burden may prove too heavy if the contingencies are greater, and the contractor may be unable to carry out his engagements. From causes such as these are owing, on the one hand, the large profits accumulated by the fortunate contractors, and on the other hand, the heavy charges which purchasers have had to bear in the transfer of contracts to new hands. Indeed, speculation is sometimes fostered by such a system, and contractors, sanguine as to the profit, may venture on undertakings whose risks may be too great for their means; and the security or sureties which may be demanded by purchasers to provide for such an event may prove insufficient, or at any rate throw the burden of loss on to others. While, however, purchasers may insist on the appraisement beforehand of risks, it is so obviously impossible in many kinds of contracts to know at the beginning the quantity of work to be done or commodities to be supplied, that some fluctuating or movable measure of value by which the price or purchase-money may be adjusted becomes necessary.

Preliminary calculation of quantities. *See also page 6.*

Contractor's risks.

Fluctuations in prices. *See page 33.*

Works prove difficult.

Unsuitable risks. *See Chaps. I. II., Part I.*

Disadvantageous to purchaser.

Speculation fostered.

Appraisement in advance impossible.

(*b*) *Schedule Rates*, or the purchase of commodities by units of price, instead of for a fixed sum of money, is often convenient and even

Purchase by schedule rates.

Simple instances. necessary. Thus, to take a simple case, a cargo of coal may be bought at a rate per ton, buyer and seller, who know approximately the tonnage, being alike indifferent when they make the bargain as to the exact quantity which the weighing after purchase will disclose. Or, a contract for the construction of a railway tunnel may be made at agreed rates per cubic yard for excavation of different kinds of material, the proportion of each kind being unknown when the contract is made, leaving for measurement as the work proceeds, or after completion, the quantities achieved. A schedule is sometimes preferred to a fixed sum merely to save time, as a manufacturer or contractor will more readily estimate the cost of certain work per unit than the total sum, which can only be arrived at by an exact calculation of quantity from drawings. Or, schedule rates may be sufficient to allow comparison between competing tenders, and the trouble of calculating and agreeing on the quantities may be taken only before the contract is entered into. But if there be many items in the schedule, it is often difficult without an approximate knowledge of the quantities to compare such tenders. Sometimes a schedule is preferred to an absolute sum, not to save the trouble of calculating the quantity in advance, but because it may be difficult to carry out the work exactly in accordance with calculated quantities. Thus, a large iron roof or bridge may be purchased at a rate per ton, the manufacturer obeying the drawings set before him, but being paid on the actual weight supplied; for as it is difficult in rolling or casting iron to arrive exactly at a calculated weight, a purchaser may prefer to pay only for what he actually receives; protecting himself perhaps by prescribing the limits of variance he will allow from the calculated quantities. Sometimes a fixed sum is adopted as a basis, and an addition or deduction allowed within certain limits to correspond with the actual quantity supplied. Thus, if the agreed price for an iron structure be £10,000, and the calculated weight 500 tons, £1 may be added or deducted for every hundred-weight of excess or diminution in weight, and the right of rejection be reserved if the difference either way be more than 20 tons. But sometimes the condition is made to apply to one side only, a deduction being made for short weight, but no addition allowed for excess. There are other cases in which an engineer intends to decide on the method and extent of works only as they proceed, and makes an imaginary schedule list of quantities to serve as the basis of a contract. But it is always desirable to approximate as nearly as possible the quantities in

Schedule adopted to save time.

Schedule tenders compared.

Difficulties.

Schedules to allow for variations.

Limit of variance.

Fixed sum as basis.

Additions and deductions.

Imaginary list of quantities.

advance, as any great alteration from the anticipated quantities may cause loss to one side or the other. For instance, an engineer who wishes to have free scope for designing as the works proceed, may state as a rough guide to contractors certain quantities of excavation, masonry, and ironwork, and ask for schedule rates to be appended to each. Probably the items of which there are the largest quantity will be valued at the cheapest rate. But if, as the works proceed, the quantities be reversed, then the contractor will lose in having to do small quantities at the low rate, and gain in the great quantities at the higher rates, and unless—which is unlikely—the alterations balance each other, there will be loss to one of the two parties to the agreement. And there is also the contingency that the works may be so increased as to be beyond the means of execution of a contractor quite capable of performing the anticipated work.

Risk of loss on one or other side.

Causes of loss.

A schedule may be summarised in one or few items, or may be indefinitely extended, each method having its conveniences. As an example of the first plan, certain goods which are to be purchased may, in regard to material, be of three kinds—iron, wood, and brass, and three schedule rates may suffice for measuring the price, even though there be a variety of each kind. Where the extent of the contract is sufficiently known from the commencement—for instance, where it is fully described by drawings or specification—such a limited schedule may serve, because, although the cost of the various kinds may differ, a contractor has an opportunity of calculating an average rate for each of the three items. But when the schedule is to be the measure of price for additions or omissions, whose direction and extent are unknown till they arise, the schedule would be likely to prove insufficient and inequitable, because all the articles comprised in the alteration might be of extremely high or low value, and the average rates therefore would not be fairly applicable. Although a minute division of the items may, as the schedule most likely to provide for every contingency, be considered the most effective, its very minuteness may be the occasion of difficulty. Thus, if some extra commodity or work be required, to which no item in the list exactly applies, a new measure of value will have to be agreed upon, while a summary schedule which classed everything of one material together would include it. In the case of an undertaking of a varied nature or which is likely to be protracted, it is sometimes sought to provide for items which may arise, not embraced by the schedule, by stipu-

Short or summary schedules.

Sometimes sufficient.

Insufficient schedules.

Minute division difficult.

And inconvenient.

Unforeseen items, how paid for. lating that their cost price shall be disclosed and proved by the contractor, who shall be reimbursed his actual expenditure with a specified addition for establishment charges and profit. This method somewhat resembles that of "Measure and Value" which will be presently referred to.

See page 30.

Grouping of items in schedule. Care and skill are needed in the division or grouping of the items in a schedule, so as to state each in the manner most suitable. There are accustomed units of measurement for different commodities, but knowledge of particular trades is necessary to their application. Not only are different articles or materials measured differently, but varieties of the same commodity also differ. Thus, ironwork is generally sold by weight, but for certain forms a lineal measure is employed, and occasionally—as in the case of buildings or roofs—superficial area. So timber is, in its earlier stages of preparation, sold by cubic contents, but when worked into certain forms, by lineal measure, and in others—such as flooring—by superficies. To the uninitiated, the classification sometimes may appear arbitrary or unnecessarily varied, but it is generally the outcome of long experience which has become expressed in trade custom. It is generally advantageous for the purchasers to adopt the measure usual in the trade, although cases sometimes arise where an analysis of the rates so stated may prove their unfairness, and some other measure of price may become expedient. Traders are generally averse to unaccustomed measures of quantity or price, and much foreign trade is lost by those who are unwilling to render their accounts in the manner preferred by the purchaser. Sometimes one kind of article has to be divided, and different methods of measurement applied. For instance, iron columns are generally sold by weight, but if on some or all of them elaborately ornamental capitals be required, these would be more fairly valued at so much each. Or, if timber or stone in a building be purchased by cubic measure, some fine carving would need another kind of appraisement. Indeed, where the cost of labour bears an unusual or extreme proportion to that of material, sale by weight or mere quantity of material is generally inappropriate.

Various units of measurement.

Customary measures.

See also page 15.

Traders averse to new measures.

Subdivision for measurement.

Proportion of labour to material.

Imperfect schedule misleading. An imperfectly-drawn schedule not only renders an estimate of cost difficult, but often hinders the proper comparison of numerous tenders; and even although the total price demanded in each may be arrived at, an investigation as to which would prove most favourable in the event of extras or omissions may be difficult or impossible. If, for example, tenders be invited of prices for a schedule of one

hundred items, of which no quantities are stated, it will be dangerous to assume that the tender which is lowest for the majority of items is really the cheapest; for even though cheaper for nine-tenths of them, yet if the quantity required of the numerous low-priced items be small, and the quantity of high-priced items large, the apparently cheapest tender may prove to be not so. Railway companies and others, who purchase regularly stores of various kinds, often invite tenders, which are to be binding for one or more years, and a properly framed schedule should, for such a purpose, state approximate quantities, or, if no nearer guide be possible, the actual quantity of each article which has been purchased in past years. If one dealer has a knowledge, not shared by his competitors, of the relative quantities, he is evidently favoured. For if, secretly informed that of certain items large quantities are to be purchased, high prices are appended to them, while for the much more numerous items, low prices are appended, a high tender may be made to appear the most favourable one to those who adjudicate. Provision is sometimes made, in contracts for long periods, for adjustment to meet fluctuations in the value of materials. Thus, the regularly published prices of some leading commodity may be taken as the standard, and the contract prices, though not similar in amount, may, in regard to fluctuations, be made to follow such published prices.

Schedule without quantities.

Fallacious comparisons.

Approximate quantities.

Corrupt dealings in tenders.

Tenders subject to adjustment for fluctuating values.

Ordinary money units are not, in some cases, small enough, and percentages of increase or diminution have to be employed for adjustment. Thus, for example, the measure of quantity for certain commodities may be so small as to require units of pence as the price; and farthings as the smallest denomination may not allow with sufficient minuteness for subdivision or fluctuation. But the price having first been stated as nearly as may be in money, the aggregate sum for which a quantity of such commodities is sold can then be further altered by one-hundredth parts or fractions of one hundred. Indeed, in certain trades the whole adjustment is so arranged, and permanent price-lists are adopted by all dealers, fluctuations in cost or the competitive prices of traders being entirely expressed by percentages. It is to this custom that the apparent anomaly is owing of prices being sometimes subjected to diminution of as much as 80 per cent. The adoption of the decimal system of coinage, which allows of infinite subdivision, would render this double and somewhat clumsy method unnecessary. Besides the trouble it involves, the plan has the disadvantage of facilitating overcharge by retailers, who, by exhibiting

Money units not small enough.

Adjusted by percentages.

Permanent price-lists so adjusted. *See* TUBES.

Disadvantages.

printed price-lists to uninitiated purchasers, may obtain far more than a usual or legitimate profit.

Percentages added.

Adjustment by percentage is in the majority of cases downward, but sometimes it is upwards. Thus the price of sea-freight for merchandise is usually subject to an addition, known as "primage," of from 5 to 15 per cent.; and this, which probably in its origin was an independent charge for some separate service, is now merely a part of the price. A peculiar system of schedule, with fixed rates, is adopted by certain Government departments where contracts for repairs or other services, whose extent cannot be ascertained in advance, are continually occurring. The schedule embraces such items of labour, material, or other commodity, as have been found by experience to be required; and against each item is a printed price or rate, each competitor being required to state at what percentage above or below the printed rates he will execute the work or supply the commodities; and the most advantageous offer is so ascertained. The quantity of work done is measured, and the bill drawn up at the printed rates, and the percentage added or deducted at the time of payment. This method is adopted partly because it suits peculiar systems of account-keeping; but mainly, as already stated, because the ordinary money units are not, in the case of certain commodities, sufficiently minute.

Schedules with fixed rates.

Percentage added or deducted.

Reasons.

Bill of quantities used as schedule.

Where an elaborate or detailed bill of quantities is provided as the basis of a contract, and where the price has to be stated in one total amount, it is often considered that the bill, with a rate appended to each item, will form the best possible schedule for any additions or omissions which may be afterwards made in the contract. To carry out this plan, each competitor is called upon to deposit with his tender the detailed bill of quantities so priced out; although generally the deposit is under seal, which is only opened when the need arises, and in the case only of the competitor whose contract is accepted.

Deposited with tender.

Difficulties in framing schedule.

But there are certain engineering undertakings in which it is very difficult to frame a schedule which shall apply fairly to additions or omissions. The custom of including every charge in a rate according to quantity demands, in some cases, peculiar subdivision to make it safely applicable. Thus a contractor may have to provide expensive plant, machinery, and apparatus, the extent or cost of which would be but slightly altered if the quantity of work were to be diminished or increased. Therefore, having these fixed expenses already provided for, extra work could be performed at less rates than those in

Valuing additions and omissions.

the primary contract, while deductions in price for omissions should also be made at a less rate, because the contractor would only save the material and labour deducted, and not a like proportion of his apparatus and fixed charges. To meet cases of this sort three schedule rates may have to be agreed upon for one item. An example of this kind would be afforded by the case of a harbour or jetty, in which timber piles may be scheduled at a price per cubic foot. In this item the contractor must include a proportion of the numerous fixed charges which have to be incurred, but of which only some pertain immediately to the piles. Thus, the cost of boats, staging, and appliances, as well as superintendence, risk of wreck, or delay from storms, have to be provided for; and accordingly a price per cubic foot is stated which may for timber seem very high. Now if, after having provided for staging and machinery, the engineer diminishes the number of piles or reduces them in size, a deduction at the primary schedule rate would deprive the contractor of more than he would save by the deduction; while, on the other hand, if the quantity of timber were much increased, the schedule rate would give him too much. And even if a separate schedule rate per lineal foot of driving the piles be provided, the same discrepancy occurs in alterations of the length driven, as not only the staging and machinery have in any case to be provided, but the piles prepared, conveyed, and pitched in place, whatever be the depth to be driven. Experience in particular kinds of works, and a mutual consideration between engineer and contractor, will alone allow an equitable adjustment in such cases.

Differential rates.

Instances.

See PILE-DRIVERS.

One schedule rate inapplicable.

Rates varied and subdivided.

Schedule rates are of great service in diminishing the uncertainty of charges, even when they cannot exactly regulate them. Thus, although it is often difficult to estimate beforehand the expense of repairs, at least many of the rates may be agreed upon in advance. For instance, if a steamer is to be repaired or refitted in a dock, the rent of the dock per day, the wages per day of the different artificers, and perhaps also the prices of material, may be arranged, thus affording the employer considerable check on the charges. But schedules of prices, unless made subject to addition or alteration, seldom prove sufficient for repairs; for the discovery of unforeseen defects, which may also have to be repaired as the works proceed, the consequent delay, and other circumstances would often operate unfairly against one or other side.

Partial use of schedules.

As in the case of repairs.

How limited.

Measure of price by units of contents.

(*c*) The measuring of price by ***Units of Contents*** is necessary in the commerce of certain commodities, liable to variation in their composition or richness, which can only be conveniently ascertained after purchase.

Where applied.

It is chiefly raw materials or chemicals that demand this kind of appraisement; alkalis and mineral phosphates being among the most important of the latter.

Valuing ores by analysis.

As an example of the former, the value of ore obviously depends upon its richness; and as the produce even of the same mine continually varies, or is combined with a varying amount of other ingredients, an analysis of each lot purchased can alone determine its value. Of course there are simple cases where long experience has proved that an average quality may be depended on, and where this happens with ores of low value, an occasional analysis may be considered sufficient, especially if the ore is to be used in the vicinity of the mines, so that the results will soon be known.

Variable quality.

But if the ore be variable, or contain ingredients differing in worth and liable to vary in their proportionate quantity, careful analysis can alone determine their value for any particular purpose; and as it would be inconvenient and expensive for a seller and buyer to examine and analyse with sufficient minuteness before bargaining, it is usual to buy while the exact quality is at yet unknown, and to agree on a price to be paid for each unit of one or more ingredients, the amount of which the analysis will disclose.

Price per unit.

Sale of chemicals by simple units.

In the sale of chemicals, payment is usually made for the aggregate of units at an agreed rate per unit. Thus a sale of mineral phosphate may be made at 12d. per unit per ton, and if analysis shows 65 per cent. the price will be 65s. per ton, and if 60 per cent. 60s. per ton. But in the case of ores it is usual to make the contract at a certain rate per ton, and then to add or deduct according as the analysis shows more or less than the standard of quality that may have been agreed upon.

Ores sold on basis of price per ton.

For instance, a contract may be made for iron ore at the price of 10s. per ton, on the assumption that it will yield 60 per cent. of metal, and it may be stipulated that for every unit above and below 60, 3d. per ton shall be added to or deducted from the price.

Adjusted by units.

The two parties to the transaction are generally willing to make a bargain of this kind, because they are aware beforehand, within moderate limits, of what the quality will actually be, for the unit price may not be appropriate beyond moderate limits. For instance, if the metallic yield of the ore be less than 50 per cent., the purchaser may have the option of refusing it, for the expenses of fuel, manipulation, and carriage may render such ore almost valueless. Or, instead

of having the right of absolute rejection, it may be stipulated that the rate per unit to be deducted shall increase as the quality becomes poorer. On the other hand, a very rich ore may be worth more than is represented by the ordinary unit price, so it may be agreed upon that for every unit of contents above 65 per cent. 5d. shall be the rate of increase in the price per ton instead of 3d.

Graduated unit price.

A contract of this kind, based on what may be called simple units, does not, however, suffice for ores not depending for their value merely on their gross metallic yield, and adjustment of price by compound units becomes necessary. Thus, for steel-making, a particular ore may be purchased because of the manganese it is supposed to contain, in addition to the iron which is primarily necessary. As an example, such ore may be purchased at a nominal price of 12s. per ton, on the basis of 30 per cent. iron, and 15 per cent. manganese, subject to an addition or deduction of 3d. per unit for more or less iron, and 9d. per unit for more or less manganese, the purchaser having the right of rejection if either of the ingredients or the total metallic yield fail to reach certain specified percentages. There may be also the stipulation just referred to, that the unit price may be increased when a certain richness is exceeded.

Simple units not always sufficient.

Compound units.

Instance.

In contracts for large quantities of ore, on such terms as those just described, the correctness of the analysis is of the highest importance, both to the seller and buyer, and the correctness of the sampling is of no less importance, and is a matter of real difficulty when the substance is not homogeneous. To take from a cargo of five hundred tons a sample of 5 lbs., requires not only honesty and care, but skill, only acquired by long practice. Representatives of both seller and buyer are generally present to assist at the sampling, which is effected either at the mine, at some place of transfer or shipment, or at the place of delivery. It is usual to agree upon a sample as correct before proceeding to the assay, as complicated disputes would otherwise arise. A sample is generally divided into three parts, one each for the seller and buyer, who each employ an analyst, and the third, in case of dispute, for the analyst who is appointed as umpire. Sometimes, however, the result of one impartial examination is agreed upon as the basis of an invoice.

Correctness of analysis.

Sampling.

Analysis of sample.

Disputes sometimes arise in contracts of this sort from an alteration in the ore after the sample has been taken. When exposed to change in weather or climate, or to the vicissitudes of a sea voyage, ore—especially if it be in a loose powder state—will absorb moisture. A

Disputes.

Alteration after sampling.

shipowner or carrier, whose freight is paid on gross weight, is not always disposed to protect his cargo from moisture. Disputes sometimes arise in regard to the added or deducted units, upon which the possible profit to seller or buyer may entirely depend. To be quite safe, a purchaser should assume as likely to occur the worst result from the analysis which the terms of the bargain allow, for, presumably, the unit tariff has been arranged so as to meet fairly any results which the analysis may disclose.

Unit tariff should always serve.

Scientific methods.

The application of scientific methods to commercial valuation has enhanced greatly the necessity for qualified analytical chemists, whose services are likely to be in increased request both for this purpose and for the processes of manufacture.

Payment by results accomplished.

(*d*) *Payment by Results accomplished* may be agreed upon, either on the basis of a sum of money, or by schedule rates; but such an agreement generally differs from ordinary contracts for the supply of commodities or the performance of works, in that the method is left entirely to the contractor, who, moreover, may not be entitled to any remuneration whatever if he fail in attaining the specified result. Thus, the pumping-out of a dock or lake, the recovery of sunken treasure, the raising of a sunken ship, the finding of minerals in a doubtful mine, the deepening of an estuary, the removal of a river bar, or the navigating some small or peculiar vessel across the sea, are speculative works which may be undertaken under this form of contract. This method of payment is sometimes adopted by public bodies and others, who have not the right or inclination to spend the funds entrusted to them on undertakings whose success is doubtful; and as it may be difficult or impossible to make a separate contract of insurance to cover the risk, they accept the offer of some speculative contractor who takes the risk of failure, but who demands in consequence, remuneration in the event of success which will leave a more than ordinary rate of profit. To the spirit and enterprise of such contractors, the carrying out of many important works which would not otherwise have been attempted is due.

Instances.

Reasons for using this method.

Speculative contracts.

Advantages.

Payment by measure and value.

(*e*) *Measure and Value* become necessary for arriving at a price where no contract has been made; and even in undertakings for which schedule rates have been agreed, goods, or works, or services, not contemplated or provided for in the schedule, demand this kind of appraisement.

A buyer may by his own knowledge, or by a trust in the fairness of the seller, be so satisfied in regard to the charges as to pay them without demur; or a price may be arrived at by haggling; or, failing agreement, the evidence of experts who measure and value the commodities may become necessary. The buyer sometimes seeks to check the charges of the contractor by keeping an account of the workmen's time and measuring the materials as they arrive. A seller is only entitled to a reasonable price, and in case of dispute must prove that his charges are fair. On the other hand, a buyer who has taken delivery of goods without previous agreement as to the price, cannot return them when he learns the price, but can only require that they be impartially valued. Arbitration is generally appealed to in disputes concerning value; and in England, even when a legal tribunal is preferred by the litigants, judges are disposed to encourage, and sometimes almost to enforce, the reference to an arbitrator rather than to a jury. The provisions made in engineering contracts for arbitration are often directed specially to disputes in price, and, if fairly arranged, afford a convenient mode of settlement. But it is essential that the appointment of the arbitrator and the conditions of hearing shall command the confidence of both sides.

Price, how arrived at.

Contractor's charges checked.

Only entitled to reasonable price.

Arbitration.

See page 9.

CHAPTER XV.

CONTRACT AND PURCHASE (CONTINUED), PURCHASE FOR EXPORT.

Technical difficulties.

IN the conduct of the engineering trades there are involved technical considerations unusual in ordinary mercantile affairs; and difficulties arising from this cause are increased in the case of foreign transactions.

Purchases for public works.

Where the demand from abroad is connected with large public works, as, for instance, where railway material or equipment is required, it frequently happens, especially in connection with large and long-established undertakings, that for obtaining what is required a complete organisation exists.

Organisation for purchase.

If England be the country of manufacture, there are engineers ready to design or specify; Government or other officials to buy, inspect, and forward; bankers to provide funds; and, indeed, every means by which economy and fitness may be ensured.

Officials and agents.

Not available in small undertakings.

But in new and smaller undertakings, and for the multitude of private enterprises in foreign countries, such a complete organisation is obviously impossible, and it is to cases of this sort that the following remarks are directed.

Subdivision of trades.

There is an increasing tendency in all trades towards subdivision, and factories are confined to the production of a few specialties where formerly miscellaneous work was undertaken. Special tools

and processes are continually being introduced, and almost invariably the manufacturer who by these means does his work best, does it cheapest also. It is very difficult for a purchaser in a distant country, even if he be an engineer, to keep himself acquainted with the changes and improvements that are constantly occurring in the country of manufacture; and if not an engineer, it is almost impossible. To these difficulties must be added the fluctuations in prices, which are peculiarly inconvenient when intercommunication occupies much time.

Constant changes.

Fluctuations in price.

The prices of all manufactured commodities are, of course, greatly dependent on the current prices of material, notably—in the engineering trades—of iron and coal. In the twenty years ending 1880 prices have at times been double those at another. The normal prices of manufactures are determined by the cost of production and the amount of profit which will tempt manufacturers or sellers to carry on the trades in question; but the current prices and fluctuations depend, not upon the cost, but upon the demand; for if this be greater than the supply, sellers have the advantage until time enough elapses to allow new factories to be built or the supply to be increased. On the other hand, if the demand be slack, the competition of manufacturers who wish to keep their factories employed, or of dealers who must sell their stock, will bring down prices to or below cost.

Normal prices, how determined.

Current prices depend on supply and demand.

The prices of plain or of heavy goods, in which the value of the material is large in proportion to the labour expended on it, obey immediately (when trade is in a normal condition), by rising or falling, every alteration in the price of material. But where only a small proportion of the total cost is for material, slight fluctuations in the value of the latter have little or no effect. Thus, the prices of railway chairs or heavy iron pipes will vary from day to day with the rates current for pig-iron; the prices of bar-iron will follow rather more slowly, because other outlay—such as that for puddling—comes between; while the selling-price of a steam-engine may remain the same though pig-iron rise or fall ten shillings per ton. But if any great alteration occur in the cost of material, or if even a moderate alteration be long maintained, the prices of the finished commodity will alter also, not merely because the material has an enhanced value, but because a considerable or long-maintained rise usually signifies a general briskness of trade. Such fluctuations in the cost of material are of special consequence in international transactions,

Prices follow cost of material.

Some prices follow slowly.

Fluctuations inconvenient in foreign dealings.

because much time may elapse before a bargain can be concluded.

Offers kept open. A manufacturer of railway chairs could not, without risk of loss, keep an offer open for acceptance for longer time than a week, unless the tendency of prices was obviously downwards, or unless he added to the price something by way of insurance, thus, in effect, making the offer a speculative one. A manufacturer of bars or plates, to whom the price of pig-iron is not of such immediate consequence, could venture further than the maker of chairs, and would probably, in a similar condition of the market, hold the offer open for a fortnight; a maker of bridges perhaps for a month; while a locomotive-builder would seldom hesitate to leave an offer of price open for acceptance for three months, though, in all these cases, there would be a risk that during the interval the factory might become fully occupied with other work.

Transactions by telegraph. If it is desired to avoid these disadvantages of distance by the use of the telegraph—and the telegraph is becoming every day more used in the transaction of foreign business—care must be taken to avoid ambiguity. Where the transaction is one frequently occurring between regular correspondents, the conditions and details may generally be arranged in advance by letter, leaving only the bare statement of price to follow by telegraph.

How arranged. It is unnecessary to describe here the elaborate and ingenious codes by which telegraphic communications are facilitated and cheapened. But where no preparation has been made in advance, then the telegraph should, if possible, be only used in one direction, full details being given by letter in the other. The circumstances of each case must determine whether the inquiry or the reply should be by telegraph.

Engineering material, choice for export. In choosing engineering material or apparatus of any kind, and for any situation, there are always circumstances to be considered other than the direct or immediate purpose for which they are required; and when the articles chosen are for export to a foreign country, these second or subsidiary incidents become more numerous. The weight which any or all of them may have depends, of course, on the circumstances of each particular case. It may, however, be convenient to summarise them here as follows:—

1. The Cost and Risk of Sea Carriage. *See page 35.*
2. The Import Duties which may be Imposed. *See page 38.*
3. The Difficulties and Cost of Transport Inland. *See page 39.*
4. The Difficulties and Expense of Erection, Setting to Work, or Treatment at the Destination. *See page 40.*

5. The Exigencies of Locality, Climate, or Space. *See page 42.*
6. Methods of Payment. *See page 42.*
7. The Rate of Exchange of Money. *See page 45.*

Sea carriage.

(1) *The Cost and Risk of Sea Carriage.*—The prosperity of a manufacturing country depends as much upon the facilities for shipment as upon the facilities for manufacture. The vast number of vessels engaged in the general carrying trade to and from English ports, afford opportunities for shipment to all parts of the world which no other country possesses. The rivalry of continental manufacturers with those of the same trade in England is largely neutralised by the expenses and inconveniences which attend the carriage and transhipment of goods from the continent. The price at the place of destination is that which really interests the purchaser, and the cost merely at the place of manufacture will, if taken alone, mislead, as it is only one of many incidents which must be considered together. The price of freight is determined by a variety of circumstances, some of which, at first sight, appear to have little relation to the matter. The primary conditions are the size, shape, and weight of the pieces to be carried, and the length of the voyage; and where the export of the goods in question forms a regular staple trade of importance, the cost of freight is mainly determined by these conditions, although the actual price of freight—like that of any other commodity—is liable to extreme variations if the demand suddenly grow or diminish. But it is seldom that material connected with the engineering trades is alone sufficient for complete cargoes, and the shipment of such material either only forms in each case part of a cargo, or, as in the case of large quantities of rails or other railway equipment, is effected by chartering a vessel specially for the voyage. Engineering material is generally heavy in proportion to its bulk; and where this is the case, shipowners, while they would be averse to taking a shipload of it, are glad to have it with other cargo, because of its utility as ballast. Variety in the *kind* of merchandise conveyed, tends much to cheapen the cost of sea carriage, for both light and heavy goods are needed for the advantageous stowage of a ship. It is because woven fabrics and other light merchandise are exported so abundantly from England, that the products of the engineering trades are conveyed so cheaply. The freight for heavy goods is charged by the ton of 20 cwt., and for light or bulky goods by the measurement ton of 40 cubic feet, the shipowner having the option

Shipping facilities in England.

Rates of freight, how determined.

Miscellaneous cargo.

Chartering.

Heavy goods useful as ballast.

Weight and measurement tonnage.

Special contracts for freight.

of choosing the method which gives him the highest freight. Sometimes, however, special contracts are made by which weight only is reckoned, this course, for instance, being expedient sometimes in the case of bridgework or pipes, where some of the pieces, if strictly measured, might be charged at rates unduly high. For very heavy or bulky pieces, such as locomotives, boilers, or thrashing-machines, ordinary rates do not apply, and a special bargain is made. The current rate of freight depends also on the likelihood of a profitable return voyage. As in an inland trade reciprocity cheapens transport, so in a foreign trade, low rates of freight outward are only possible where imports are encouraged; an unrestricted intercourse between nations, and the consequent employment of ships, being among the benefits which a wise policy of free-trade affords. Thus, if there is a heavy crop of tea in China, or of cotton in India, so many vessels may in each case start to fetch it, as to make outward freights cheap. The profitable return voyage, to have this effect, need not even be to the same country. For instance, the selling price at Philadelphia of Spanish iron ore (of which large quantities have been sent to the United States) will be affected by the fluctuations in the price of wheat in London, because high prices in England encourage the export of corn or flour from America, which, as it causes an increased demand for vessels, enables the shippers to charge higher freights to England, and the prospect of such corn cargoes, inducing an increased number of European vessels to cross the Atlantic to fetch them, has the effect of reducing freights westward. On the other hand, freights sometimes suddenly rise because of a demand in another direction. Thus, to take a similar example, if much corn await shipment in Odessa, vessels will be attracted thither instead of westward, and freights to America will rise.

Free-trade reduces freight.

Return cargoes determine rates outward.

Instances.

Proximity to port of shipment.

Land carriage dear.

Choice of port.

In making contracts for machinery or engineering material, the proximity of the factory to the port of shipment must be considered. The cost of carriage to the port often amounts to as much as, or more than, the freight by sea to a distant country; and this circumstance, of course, is of increased importance for those commodities in which the expense of carriage bears a considerable proportion to their total cost. Where the goods are in large quantities, as is often the case with coals or railway material, a vessel may be sent to the nearest port to fetch the cargo, instead of the cargo being sent to a port which suits the vessel. For instance, in England, steam coals and

railway iron are shipped from Newport and Cardiff; coals, pig-iron, and pipes from the Tyne, the Tees, and the Clyde; while the largest proportion of machinery and general engineering material is shipped at London, Liverpool, and Hull. At whatever port cargoes are lying, vessels may, as just mentioned, be chartered to go there and take them. But even where the goods offered are not sufficient to fill a vessel, they may be enough to induce a shipowner to send his vessel to call at a particular port to fetch them, to complete a cargo commenced or finished elsewhere. But although vessels to any foreign country may sail indifferently from any British port, it has become the custom, either because of the exigencies of the homeward trade, or because certain harbours are suitable for the vessels in question, or for other economical reasons, that particular trades or destinations are associated with particular ports of departure, and the larger proportion of machinery shipped from Great Britain has to go with other and miscellaneous cargo from these customary ports.

English ports for coal and iron.

See COAL.

Chartered vessels.

Customary ports.

The strength of the goods to endure the risks of transit; the order or sequence in which shipments shall be made; the best methods of packing; care in loading; the security of stowage on deck or in the hold, are all matters which demand attention, especially in the case of heavy, bulky, or fragile cargo, such as boilers, locomotives, or roof-work.

Order of shipment.

Packing and stowage.

When cargo is shipped, bills-of-lading are signed, by which the owner or agent of the vessel undertakes to deliver the goods at their port of destination in good order and condition, unless certain accidents or events which are specified in the bill-of-lading, relieve him from his liability. Shipowners frequently seek to reduce their responsibility as carriers by introducing into the bill-of-lading special clauses, favourable to themselves; and while it is doubtful how far such exceptional stipulations can be legally enforced, it is advisable for the shipper to protect himself either by insisting on proper terms or by insurance against the loss of or damage to his goods, that may occur upon the voyage. For instance, the total cost at a foreign port of arrival of a cargo of fragile iron pipes will not be comprised in the original purchase-money, with the expenses of freight and insurance added, unless the liability for breakage be also allotted. The percentage of premium paid for marine insurance is determined by various conditions, such as the direction and probable duration of the voyage, the age and character of the vessel, the nature of the cargo, and in some cases by the season of the year in which the voy-

Bills-of-lading.

Liability of shipowners.

Special provisos.

As to damage.

Liability should be allotted.

Marine insurance.

Premiums.

age takes place. Insurance can be effected to include, besides the risk of total loss, that of partial damage (if amounting to 3 per cent.), when it arises from perils of the sea; and on ordinary merchandise, it is generally advantageous to insure in this way, technically called "insuring with average." It is usual however to exclude this part of the risk when insuring iron or rough cargoes, policies being then effected "free of particular average" (f. p. a.), the underwriters being then freed from liability for partial damage, unless "the vessel be stranded, sunk, or burnt," in either of which cases the underwriter has to pay for the damage or expense, whether it arise in consequence of this special casualty or not. It need hardly be said that, other circumstances being equal, the premium is larger in the case first mentioned than in the second. In voyages to the East Indies, China, or the Australian colonies, premiums hardly vary at all on account of the season of the year, but on shipments to the Baltic or Black Sea, to North American ports or to the West Indies, the rates of premium are very much higher on vessels sailing in the winter.

Particular average.

Fluctuations in premium rates.

Advantageous to buy high-quality goods only.

Where the expense of freight and insurance is considerable in proportion to the cost of the goods at the place of manufacture, it is obviously unprofitable to obtain a small saving in the original price by accepting goods of an inferior quality. Thus, if ten per cent. be saved in the cost of the goods with a presumable equal reduction in quality, it may be found, when the freight and charges have been paid, that the saving when calculated on the total outlay is only five per cent., while the reduction in quality still remains ten per cent.

Import duties.

Protective duties.

(2) *Import duties* are imposed on machinery and engineering material in almost all countries, either for the purpose of revenue, or for protecting home manufactures, or for both these purposes. The fallacious reasoning and the false economy by which protective imposts are excused, have long been understood and repudiated in England; but such taxes are still maintained in many foreign countries, chiefly through the influence of the few who benefit by them, the majority of the people not understanding how the taxes which are apparently paid by foreigners are borne (with the addition of many expenses) really by the country which imports. The fact that the evil effects of such protective dues on the importing country are, directly and indirectly, largely in excess of the apparent gain, is gradually being understood by the more intelligent in such countries,

Evil effect of protection.

See page 53. Also page 2, Part I.

and there is a tendency in some towards the removal of these imposts. The burdens inflicted on the community for the supposed advantage of particular trades, are so great, as to hamper them greatly in competition with free countries where there is a general liberty of purchase. The existing state of things, however, has often to be considered in the export of engineering material. Sometimes the dues are levied *ad valorem*; in other cases they are calculated at a fixed rate by measure of weight or quantity, according to the nature of the material; and the merchant or importer has to be guided not by what is best suited to the purpose in view, but by the necessity of entering under a low tariff. Thus, it is possible sometimes, to obtain an advantage by substituting one kind of material for another, as, for instance, cast for wrought iron. Where customs dues are imposed without discrimination according to the kind of material of which the goods are made, and not graduated *ad valorem* according to the different qualities, it is to the interest of the purchaser to import material of a high quality. As an example, if the price of good tool-steel be 9d. per lb., and an inferior quality be only 4d. per lb., and if the duty on both be 4d. per lb., it is obviously economical to purchase the best. In other cases, the goods imported may, by the omission of certain workmanship, be brought within the lower tariffs which prevail for raw material. For instance, in an iron bridge, the bars or plates may be sent without any holes punched or drilled in them, and so in some countries be admitted at a much lower tariff than would be imposed on the finished article. It is true that the addition of such holes, and the after fitting together of the structure, may only be effected in the importing country at a cost four times as great as the cost would have been in the manufacturing country, and the work be done in a less effective manner; but though this extra cost may be £5 per ton, against this perhaps £10 per ton may be saved in duty; and the real loss which this peculiar economy involves, falls actually on the importing country, and is only one of the manifold ills which such so-called protective duties inflict. Where there are imposts of this sort, the engineer or manufacturer should be furnished with the tariffs, and with a full explanation concerning those rates which bear on the case in question, so that they may help to determine the choice of commodity to be exported.

Duties how levied.

Choice of goods affected by duties.

Instances.

Low tariffs for raw material.

Loss caused to importers.

Makers guided by tariffs.

(3) *The Difficulties and Cost of Transport Inland.* There is sometimes great difficulty in transporting heavy ironwork or machinery from the

Transport inland.

See also page 49.

port of arrival to its destination, and difficulties of this sort should be taken into consideration when the machinery is designed. The question often resolves itself into a choice of evils. It must be estimated whether it will be cheaper to carry at great cost, the large or heavy pieces which are best for the ultimate purpose, or to make the pieces lighter by the use of high quality material (such as steel), or by subdivision, to make them lighter because more numerous. This latter course may render necessary the export of machines which have not been completely finished and proved, and the expense of bolting together or riveting at the site, which would be avoided by sending larger pieces.

Choice of evils.

Large pieces with costly carriage.

Or light pieces numerous.

(4) *The Difficulties and Expenses of Erection, setting to work, or treatment at the Site.* In choosing machinery or engineering material, the final cost when complete on the site, and fitness for the purpose in view, are the two principal questions which have to be considered, and there need be no hesitation to select for use in the country of manufacture what best satisfies these conditions. But in foreign countries, the intending purchaser has to consider how far he will be able to utilize his material when he has imported it, and whether he has qualified engineers or workmen to erect, set to work, or otherwise complete it. The articles in question may be so simple as to need no special skill, or may be already in such common use as to have afforded experience, and to have created a class of workmen who sufficiently understand them. The engineer or manufacturer, if properly informed by the purchaser of the circumstances of the case, can often, by slight modifications, facilitate the work which will have to be done abroad, or can advise the substitution of some things simpler than would be used in the country of manufacture. In machinery and apparatus of all kinds, improvements are continually being devised which allow economy in maintenance, or in cost of working; and while many such improvements are in the direction of simplicity, others, not unfrequently, are of a delicate or complicated nature, demanding skilled supervision. It is then of course, a question for the purchaser and for the engineer who advises him, how far it will be prudent to establish such novelties in a foreign country; and whether a ruder or simpler kind will not be better adapted to the circumstances of the case. On the other hand, purchasers, especially when they are not engineers, are apt to over-estimate the difficulties of dealing with machinery or engi-

Difficulties at site.

Choice guided by facilities in importing country.

Designs modified for foreign use.

Improved machines may be too complicated.

Difficulties often over-estimated.

neering material in a foreign country. This tendency leads them to attach too high a value to those articles which, being complete or self-contained when they arrive, need little or no skill for erection or setting to work. It is owing to this, that portable engines are used in many cases where a fixed engine would be better and more durable; that bridges which can easily be bolted together are chosen in preference to those that may with more advantage and safety be riveted; or that wrought-iron tanks (occupying much space for freight) which are ready for use when they arrive, are preferred to the stronger and more permanent tank composed of cast-iron plates that are more easily carried, but which have to be bolted together and caulked at the site.

Instances.

See BRIDGES *in Part I.*

See TANKS.

Economy in working.

The question of maintenance or economy in working has also to be considered. Thus, a structure or the framework of a machine may be better made of iron than wood, but because skilled workers in iron, who can do repairs, are difficult to obtain, the question arises whether wood may not, under the circumstances, be preferable to iron. Again, there may be used in English workshops a special and expensive machine, adapted for one particular kind of service, which it performs quickly and cheaply. But in a foreign factory, the amount of this particular work may be insufficient to afford constant employment to the special machine, and it may be more economical to import a tool which can be used for various purposes, even though, for the particular duty in question, it may be less effective. Or a steam-engine may be required in a country where fuel is very expensive, and where, by the use of a certain kind of boiler, economy of fuel may be obtained. Such a boiler, however, may need more frequent repairs and be less durable than one of a simpler form, which consumes more fuel. It is obvious that very careful consideration of the different circumstances is needed in such cases. To meet exigencies of this kind in a foreign country, duplicate machines or duplicate parts may be purchased; and it may be expedient to incur expense which may be regarded as a premium of insurance against loss, a premium which would be altogether extravagant and uncalled for in England. The number of such duplicates, their cost, and the interest on capital which the keeping them in reserve involves, must be weighed against the length of time and consequent delay which would be required to import a fresh supply.

Special machines often too expensive.

See MACHINE-TOOLS.

See BOILERS.

Effective machines costly to repair.

Duplicate parts required.

Involving capital outlay.

The stoppage of machinery, or the failure of material in the importing country, is a more serious matter than it would be in the

manufacturing country, where repairs or renewals can be easily effected; and this often applies to the smallest detail. For this reason, it is bad policy to import inferior articles, even though they be as good as would be used for the purpose at places within easy reach of repairs or replacement. Thus, in the case of wood-working machinery or the engine of a sugar-mill, the consequences of an accident might in the manufacturing country be so easily repaired as to render undesirable any expenditure of capital to provide duplicate parts. But in the importing country, such extra expenditure might be more than justified, as a safeguard against what would in effect be a serious disaster. This, added to the reasons already adduced against the false economy of exporting second-rate goods for engineering purposes, shows that the example of what obtains in a manufacturing country is not necessarily to be followed abroad.

Where repairs are difficult, inferior articles should be avoided.

Exigencies of climate, locality, and space.

(5) *The Exigencies of Climate, Locality, or Space.*—In the establishment of a factory, the erection of machinery, and, indeed, in almost every kind of engineering work, there are certain local circumstances which must be studied and satisfied if economy and fitness are to be obtained. If buildings are required, not only their purpose and a plan of the site, but also the levels, the nature of the soil for foundations, and the climate with its effects on material, are all incidents that affect the choice of design or the mode of arrangement; and where engineering material or structures have to be designed or manufactured in one country, in order to be erected or completed in another, it is obvious that full information should be transmitted to all concerned in the design or preliminary stages of the work. With such information as a guide, the necessity or expediency of altering the usual methods may be apparent, while, if such information be withheld, and only a bare enumeration of wants be supplied, the risks of unfitness or extravagance are very great.

Building materials.

See FACTORIES, *Chap. XVI. and page 70, Part I.*

Methods of payment.

(6) Unless there be some stipulation to the contrary, *Payments* for works, goods, or services, become due when the obligations are fulfilled. Deferred payments, and the speculative combinations of contractor and capitalist which often arise out of engineering projects and public works, have been already considered, and it is not necessary to allude here to the ordinary methods of payment usual among merchants. But in the carrying out of works abroad, or the manufacture of engineering material for export to a foreign country,

Contractor-capitalists.

See Chaps. II. III., Part I.

special circumstances have often to be considered. In some countries, payment of a portion of the purchase-money in advance is usual, and, as "hand-money," is, by custom or law, essential to the closing of a bargain. In countries like England, where rules of credit properly guarded and limited are established, payments in advance are seldom required, except from foreigners or others who are not domiciled. Although, where the purchaser has confidence in the seller, this plan is simple, the alternative can be adopted of depositing the money with some banker or agent, who need only pay in the ordinary way as the contract becomes completed.

Hand-money.

The nature or extent of an undertaking often renders part payments necessary as the work proceeds, and should be provided for in the conditions of contract. For instance, in the carrying out of a contract for a railway or other large undertaking, payments during construction have to be made; or in the manufacture of a large bridge of many spans, as each is delivered to the ship, site, or other place agreed upon, a proportionate sum on account has generally to be paid. If the works contracted for allow of very exact subdivision, each portion being complete and independent of the other, the payments during the progress may be the full equivalent of what has been performed. Thus, if 12 steam-engines, or 12 bridges, or 12 miles of railway are contracted for, a purchaser may be willing to pay a twelfth part as each is complete and in his possession. But in the case of a bridge of numerous spans, or of some railways, or of a dock, the different parts may be so dependent on each other, as to render inexpedient, payments on account to the full extent of the part apparently completed. It is usual, therefore, after calculating the money value of the completed work and the proportion it bears to the whole contract, to withhold some of it—a specified percentage, *e.g.*, five or ten per cent., as may be agreed—till the contract is absolutely completed. The percentage to be retained is determined by various considerations, the nature of the work and the lessened or suspended value of the earlier parts if the remainder were not completed or were much delayed, being the principal.

Part payments.

As portions are completed.

Instances.

Retention money.

See pages 36, 72, Part I.

Payments thus withheld are, in effect, caution-money (which will be forfeited if the contract be unfulfilled), the accumulation of which is, in large contracts, limited to a prescribed total; and when the percentages withheld reach this maximum, the after payments are made in full.

Caution-money.

See pages 5 and 25, Part I.

Where a contract is made in one country for the carrying out of

Part payment on shipment. works in another, whither material and equipment have to be exported, it is often stipulated, where the undertaking is a large one, or likely to be protracted, that a portion of the purchase-money shall be paid on each shipment, although, till they have arrived and been applied at the site to the purpose in view, the material so paid for may be of no value to the purchaser. **Arranged by schedules.** *See page 24.* The arrangement beforehand of the proportions payable is a matter of great importance to the contractor; and, to avoid disputes, elaborate schedules are often appended to an agreement, declaring what proportions shall be payable at the various stages of shipment, delivery, completion and at the end of a term of maintenance. And the same arrangement is often made in the case of works undertaken by local contractors in colonies or countries where the material has to be imported; **Contractors importing material.** and while the obligation and responsibility of obtaining the material remains with the contractor, the employer provides money in the manufacturing country to make the necessary part payments, taking care, by suitable agents, to ensure that the material so paid for is of the agreed kind and quality. **Payers require possession.** Where part payments are made on shipment, the payer usually requires possession of the goods; and though they may have to be temporarily re-entrusted to the contractor at the port of arrival and until completion, the legal possession remains with the purchaser.

Part delivery may be impossible. There are certain kinds of contracts where part delivery to the purchaser is almost impossible, and payments during progress cannot be met by giving possession of an equivalent part. **Instances.** A steamship or a large pumping-engine, where the total outlay may be greater than the builder can afford without part repayment, are examples. **Payment during construction.** There are certain stages in the progress of such works which indicate broadly the proportion accomplished, and it is usual to pay a portion of the purchase-money at such periods. **Instances.** For instance, in the case of a steamship, it might be agreed to pay one-fourth when the hull-frames are set up, the cylinders cast, and the boiler-plates punched; one-fourth when the ship is plated, the cylinders bored, and the boilers finished; one-fourth when the vessel is launched and the engines completed and ready for placing on board; and the final fourth part of the payment when the steamship has had a successful trial trip. **Purchasers require lien or security.** In contracts of this sort, purchasers are naturally anxious to have a lien on the property for which they have partly paid, but of which they cannot yet get possession; for in case the factory changed hands, or a mortgagee took possession, or the shipbuilder

became bankrupt, disputes might arise regarding the ownership of the property. If the purchaser happens to be the owner of the building or soil on which the ship is being built, his right to the works in progress would be clear; and as such ownership of the premises is sometimes considered the simplest or only effective security, a legal conveyance is effected and retained till the ship is delivered to the purchaser. The same result is sometimes sought by the mere deposit of title-deeds or lease, with a declaration as to the property. But all such methods are inconvenient, and the seller may be unwilling, or even unable, to agree to them. It is often, therefore, considered sufficient to affix some notice or placard to the structure in question, so as to declare plainly the ownership. And the minor parts may be similarly identified by casting, branding, or marking each with the name or sign of the purchaser. Such marking, if accompanied by *bonâ fide* evidence of purchase, and part payment, is considered sufficient to protect the property, at any rate to the extent of such payments, against the adverse claims above referred to.

Ownership of site or factory affords security.

Deposit of deeds.

Name of owner affixed.

(7) In the export of engineering material, as of all other commodities, the *Rate of foreign exchange* does much to determine money values and prices; but to the engineering trades, the question is important in other ways than those in which it affects the ordinary merchant. Engineers, contractors, and the traders allied with them are, perhaps, more than any other classes, interested in foreign undertakings; and the payments for Public works, the guaranteed interest on investments, the tariffs for Railway, Water, or Gas service, and salaries to engineers, are frequently made in the currency of the country concerned. Moreover, as engagements for matters of these kinds are often made for much longer periods than contracts for the purchase of merchandise, the risk and the effect of extreme fluctuations are proportionately extended.

The rate of foreign exchange.

Often important to engineers and contractors.

Only a brief reference to so wide and important a subject as foreign exchanges is, however, necessary or possible here. The rate of exchange between any two countries is primarily determined by their relative indebtedness, so that persons who want to remit money to a foreign country, and who have to buy in the shape of a bill-of-exchange money belonging to, or a debt owing by, some one in that country, will have to pay a price which varies according as the demand for such bills is greater or less than the supply. But in the case of countries having a similar system of currency — as, for

Rate of exchange, how determined.

Countries with similar standard.

instance, England and most of her colonies, or England and Germany, which alike have a gold standard—and where a par bullion value is established, a premium in either direction has only a moderate range, for it is limited by the cost of the alternative plan open to remitters of despatching bullion; the freight, insurance, and interest during transit of the bullion being taken into account. But when there is a different monetary basis, much greater fluctuations become possible, as is seen in the dealings between a country having a gold with one having a silver standard.

Fluctuations, how limited.

Countries with different standard.

To the ordinary fluctuations just alluded to, arising from an excess of the flow of remittances in one or other direction, is added the alteration, whose range cannot be defined, of the relative values. An example of this is seen in the commerce between England and India where a silver currency standard is (1880) firmly established. Although the relative value of the two metals has constantly varied, the tendency has, in the course of years, been towards a lowering of the value of silver; and the rapid fall in the few years ending 1880, has caused not only inconvenience but loss to many concerned; for where goods have to be exchanged for something which fluctuates in value, and which therefore can hardly be called money, the commerce takes the form of barter rather than sale, and upsets all antecedent calculations. Without entering upon the much disputed question whether a universal gold standard would be possible, it may be safely said that a double standard in any country is impracticable, and even where, as in France or the United States, a bi-metallic currency is nominally established or attempted, the evils which would arise from such a system have to be prevented by so limiting the coinage of the inferior metal as to render it unavailable for large transactions.

As gold and silver.

Fall in value of silver.

Double standard impracticable.

There is a liability to still greater fluctuations in the rate of exchange where an irredeemable paper currency is established; for although a strictly limited issue may maintain a certain level because of its purchasing power in the country itself, there is no limit to the depreciation which may result from an extended issue. The *assignats* of the French Revolution, and, in a less degree, the greenback issue in the United States during the civil war, are cases in point. The question is still further complicated between countries which, like Austria, have both silver and paper currency, and countries like England, with a fixed gold standard. A reduction in the international value of a silver or paper currency, as seen in the rates of exchange, is sometimes a great advantage to many concerned, especially in

Irredeemable paper currency.

Fluctuations unlimited.

Instances.

Mixed currency.

Temporary gain by fall in value.

large countries where such a currency has a wide circulation. For instance, in India or in Russia, if the value of the silver rupee or paper rouble fall, the peasants and others whose rent and taxes are fixed in the local currency pay for a time a sum no greater than before, while if they have produce to sell for export, they find that the price (which is determined by outside or international causes) gives them more than the usual number of rupees or roubles. But even this gain is generally only temporary or apparent, for international commerce is too extended not to bring values to their proper level in time, and the prices of commodities consumed rise. On the other hand, those whose incomes are fixed in the inferior money, but who have to purchase imported commodities, or who wish to remit to a country having a currency based upon gold, suffer to the utmost from the depreciation.

Instances.

Losses caused by falling exchange.

If, in a foreign Gas-works, the agreed price or tariff for gas is paid in the local money, while coal has to be imported at its market value, and paid for in gold or its equivalent, it is evident that a great loss results from a depreciation of the currency. Or, a Railway, or Tramway, or Bridge, made with borrowed money, on which interest has to be paid in sterling, may have tariffs and tolls fixed by law, which cannot be raised as the value of the local currency falls. Engineers, contractors, and others concerned in public works, are often of necessity obliged to accept payment in local currency; and even where British sterling has been the original measure of value, some fixed rate of exchange is often adopted as the basis of computation. It is, however, always expedient to provide for possible fluctuations by stipulating, either in general terms that the local payment shall be the equivalent of a specified sum in sterling, or with greater precision, that the payment shall follow the rates of exchange or be subjected to revision if the difference pass a certain moderate limit. There are various indirect causes which influence the rates of exchange between two countries, such as the scantiness of trade, which may limit the opportunities for remitting; the commerce of other countries with which each of the two may have relations; the uncertain credit of individuals or banks; but on these it is unnecessary here to touch.

Tariffs paid in local currency.

See page 225, Part I

Borrowed money, bearing interest in sterling.

Fluctuations should be provided for.

Indirect causes of change.

British sterling is the best basis for international transactions. London has become, not only because of her vast commerce, but for various other reasons, the clearing-house of the world; and, even to the foreigner, such a basis of computation is, because of its certainty,

British sterling.

often convenient and desirable. But the ordinary quotations for rates of exchange are seldom for bills payable at sight, the customary usance, which varies with different countries, being generally for bills of from one to three months after sight by the acceptor; and this must be borne in mind when a bill on a foreign country is purchased for ready money. It is necessary, therefore, in stipulating for payments in a foreign country, "at the current rate of exchange," to remember that the ultimate payment will only be made after an interval, during which interest must be reckoned. But a special rate for a sight-bill will generally be quoted by a banker if required, and the current rate of exchange for a banker's bill at sight on London, may be safely adopted in any country as the measure of value for international transactions.

Usance differs.

Banker's sight-bill a safe measure of value.

It will be seen from the foregoing pages that the secondary or subsidiary incidents enumerated on page 34, deserve much weight in the choice of engineering material, and that what may be the best of its kind for use in a manufacturing country is not necessarily so abroad. It too often happens that a purchaser who has seen or read of some new machine or material which has proved successful, desires to have the same thing sent to him abroad, without appreciating at their proper value the differences in circumstance which these incidents cause. And engineers also or manufacturers, who may be fully competent in the exercise of their profession, do not always give full weight to the contingencies of locality and circumstance which have been described. But although these contingencies, if known, may be provided for, unfortunately in a great number of cases they are not known to those immediately concerned, namely, those who have to design, manufacture, or supply the commodities required. The importance of sending full information from abroad, and the infrequency with which this importance is appreciated, have already been referred to.

Importance of points on page 34.

Insufficient weight given to them.

See Preface, Part I.

See page 5.

To those in foreign countries who are surrounded by the same continually recurring circumstances or conditions, and to whom the facts of locality or purpose are perfectly familiar, it doubtless requires a special effort of mind to realise on what apparently simple and rudimentary points it is necessary to inform the engineer or manufacturer at a distance, to whom is intrusted the fulfilment of their wishes. It must be remembered that in a manufacturing country where demands centre from all parts of the world, ever-varying conditions have to be

Importance of giving particulars not appreciated.

satisfied and to meet these differences there is a corresponding variety of methods. The choice among these methods depends upon local facts of which, for his knowledge, the engineer is generally dependent on what is supplied to him by those on the spot. Sometimes important dimensions are omitted: in other cases the purpose which is to be satisfied, or the service to be performed, is not sufficiently described; or the method of payment, or the conditions of site or climate are omitted altogether. Delay is thus caused while the missing facts are being ascertained; and if, to avoid delay, a somewhat hap-hazard decision is come to, then, in the desire to be safe as regards strength or fitness, an unnecessarily great expense is generally incurred. As for example, a bridge of several spans is required, and the bed of the river is either not described at all, or merely alluded to as mud or sand. Nothing is said further as to the density of the bed or its suitability for foundations; and the engineer, assuming that the mud is soft, designs his piers accordingly. The foundations may prove to be firm, and it is discovered, when the bridge is fixed, that much less expensive piers would have been sufficient. Ten pounds have perhaps been saved by omitting to examine the river bed, and five hundred pounds wasted in unnecessary screw-piles. Again, a powerful engine is required, and although the horse-power is specified, no particulars are sent as to the space into which it must fit, the service for which it is required, or the provision which is to be made for connecting it to existing machinery. Or, as regards the boiler, no information is given as to the maximum size and weight of the pieces which can be transported to the site, or as to the fuel it is to consume. Or, to take another case, iron pipes are required, and no information is afforded as to the purpose for which they are intended, the pressure to which they will be subject, or the sort of place in which they are to be fixed. Perhaps there is no grievance upon which engineers in England and the manufacturers allied to them would so unanimously agree as in regard to this insufficiency of information furnished from abroad.

Choice and design hindered.

Delay and expense caused.

Instances.

See BRIDGES, *Part I.*

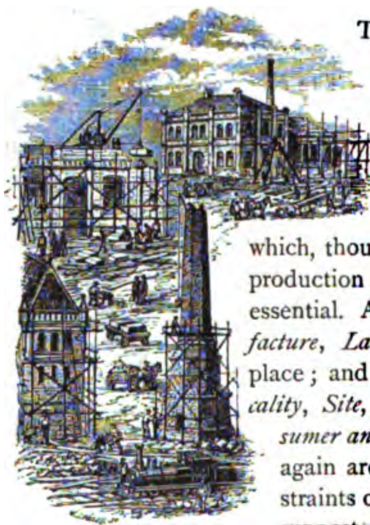
See STEAM-ENGINES.

See page 39.

See PIPES.

CHAPTER XVI.

THE ESTABLISHMENT OF FACTORIES.



Conditions classified.

THE conditions which favour the establishment of manufactories might, if they admitted of a rigid classification, be divided into those which are primarily necessary to the purpose in view, and into those secondary conditions, which, though they may determine the cost of production and the amount of profit, are not essential.

Essentials and non-essentials.

Among the first *Materials of manufacture*, *Labour*, *Fuel*, *Water* might take a place; and among the second—*Climate*, *Locality*, *Site*, *Transport*, *Contiguity to the consumer and to subsidiary trades.* Outside these again are the sufficiency of capital, the restraints of law and custom, and the artificial support of subsidies, bounties, or protective duties.

Countries, how to be compared.

In comparing the respective advantages of different countries in regard to some branch of manufacture which is carried on in both, it is necessary to consider separately these various circumstances if any useful conclusions are to be arrived at; and especially is this necessary where the peoples who are concerned have much in common. In regard to the iron and engineering trades, an example in point would be afforded by a comparison between England and either France, Germany, Belgium, or the United States.

Inventions become common to all.

Between nations such as these, of the first rank in manufactures, all the advantages of science and invention become common property; for though one or other nation may be

slow to adopt improved methods, the natural process of competition will in time lead all to do so.

Home trade may be retained.

For a home trade, local manufacturers may, if the country permits it, always have an advantage, for by protective duties such a trade may be retained at whatever cost. In regard to an outside or foreign trade the case is different, and any disadvantages which are peculiar to the manufacturing country will show themselves in the long run. But the conditions just alluded to so combine or merge into each other that an exact classification is impossible, and in the following remarks it is only attempted to draw attention to some of the more important points which should be considered by those who contemplate such undertakings. Where factories of whatever kind are already established in a locality, the conditions of profitable working are sufficiently known or may be ascertained by those acquainted with the trades in question; and failure when it occurs generally arises from an attempt to compete in supplying an already well-supplied demand; from insufficiency of capital or an expenditure of capital excessive for the purpose in view; from a non-appreciation of the examples available for imitation; or from bad management. But where a new industry is to be introduced into a country or district for the first time, the risk is greatly enhanced by the want of precedent.

But foreign trade is open to rivals.

Causes of failure.

Risks of new undertakings.

Manufacturers in new countries.

In new countries with suitable natural resources, there are generally enterprising men who desire to establish factories for the manufacture of goods which may have been hitherto imported; and there is a natural desire on the part of the community to encourage such a national trade. There are some manufactures which should obviously be established. Thus, no people would—if they could help it—remain absolutely dependent on a foreign supply for food, for bread stuffs, for munitions of war or for coining of money; and arsenals, dockyards and factories, whose primary purpose may be for warlike stores or repairs, gradually find profitable employment in new work also. It may be assumed that in every inhabited country there are natural advantages which have caused it to be populated; fertile lands or abundant minerals being those on which the early prosperity depends. In such countries, a busy people can produce much more than they can consume, and an export trade is naturally developed which brings back from older countries, manufactured commodities of all kinds for the necessities, comfort or luxury of the people; and to the thrifty and successful allows an accumulation of capital which is the basis of

Necessary trades.

Natural advantages.

Trade developed in new country.

all manufactures. Assuming that a demand for certain commodities exists or may be reasonably expected, the trades most likely to succeed in a new country in competition with imported manufactures are

Simple trades best.

those which are simple and self-contained, and are least dependent on subsidiary trades. The natural tendency in manufacture is towards a subdivision of processes by which workmen, continually engaged on repetition-work, and assisted by special tools, can produce well and cheaply; and this tendency finds its greatest development in an old

Subdivision difficult in new countries.

country. Attempts to rival such well-organised and minutely-divided industries, under less favourable circumstances, will have small chance of success. For instance, in a colony or newly-settled country,

Utilisation of local materials.

where coal and iron hitherto unworked are found in close contiguity, it might appear as if finished iron or steel might be produced more cheaply than it could be imported; and there is a natural desire to

Premature development of manufactures.

encourage such local manufacture. These local materials will have their value in the future, but government interference to develope them, except by the granting of facilities or the removal of obstacles, may involve considerable risk to the true interests of the community. For if a preference be shown to the local industry in order to induce the establishment of factories when the economical conditions are against them, the country will find itself saddled with an unprofitable undertaking when the real conditions are revealed; and bounties, subsidies, or protective duties will be demanded or perpetuated with all their attendant evils. In the older country, the processes have probably been so cheapened by subdivision and by special appliances, and the quantities manufactured are so great, that the cost of

Imported goods cheapest.

production, even including the expenses of transport to a distance, has been brought much lower than the new country can for a long

Instances.

time hope to rival. To make steel, steam-engines, or cutlery, in a new country would generally be unprofitable, even though raw material ot

See also page 60.

every kind were abundant. Rather should the tools and appliances which have, by years of accumulated experience, been brought to perfection and cheapness in the old country, be utilised in the new for those trades and processes which are primary and simple.

Goods should be bought where cheapest.

It may be laid down as a general rule that it is against the interest of a community to make at home what can be brought more cheaply from abroad; and the saving effected by adherence to this principle

Protective duties.

affords resources for more legitimate enterprise. Where taxes are

See page 38, and in Part I. page 2.

imposed on imports from abroad, not for the purpose of revenue, but as a protection to native industry, such a system, specious as the

arguments for it may appear, has, wherever it has been tried, hindered the development of the country. For a time, and in the immediate neighbourhood of the protected trades (and so long as there is a brisk demand for the commodities), there is an apparent prosperity, especially where money lent by the old countries, whose manufactures are prohibited by import dues, provides ample means for home expenditure. But while, owing to the artificial enhancement in the prices of goods manufactured under these conditions, wages may be apparently high, the purchasing power of wages is diminished by the high prices of the clothing and various other imported commodities which are also taxed. The tendency of a protective system is to spread, for it would appear unjust to protect one trade and not another. But it is seldom that the price of agricultural products can be thus artificially raised, for a tax on food is resented by the people, and the *rentier* and farmer have therefore no compensation for the taxes imposed on the commodities they buy. Manufacturers under such a system are, when they attempt a foreign trade, weighted in their competition with countries where liberty prevails. For freedom of action is that which most tends to the progress of an enterprising people; and freedom to buy in the cheapest market is one of the greatest liberties of all. And although protective duties are generally excused as merely temporary expedients, vested interests are strong; and when capital has been invested, and factories have been built on the faith of a national monopoly, the reform which must eventually come when the folly of the system becomes patent, generally involves loss to those immediately concerned. The gain to the revenue of a country by protective duties imposed on foreign goods which compete with untaxed goods at home, is of course at the expense of the importing country, though the advocates of the system sometimes maintain the contrary; and the gain to the revenue is limited to the taxes collected on the actual import; while the burden to the general community is measured not only by the revenue which they pay, but by the higher prices paid to the home manufacturers, and by the general loss to the country of the goods which are shut out by the duties. But beyond this, there is the burden for which there is no satisfactory gain to any one—of the profit put upon the import-tax by the merchants, factors, and retailers through whose hands the commodities pass; by the cost of customs collection; by the demoralising evils of smuggling; and the general restraint of trade which Government interference always involves.

Apparent prosperity.

High wages neutralised by high prices.

Burdensome taxes.

Liberty to buy cheaply withheld.

Vested interests created.

Burden of taxes more than the gain.

Evils of taxes and restraint of trade.

See also page 55.

Bounties. Native industry is sometimes encouraged by bounties on production instead of by taxes on imports, and this is really a cheaper and more logical application of the protective principle; for such bounties being paid directly out of national funds, instead of, as in customs revenue, by indirect taxes not so palpable to the consumer, the amount expended may be exactly calculated; and the indirect losses to the community above referred to are not incurred. There is also **Fallacy evident.** this great advantage under the bounty system, that the fallacy of protection is sooner recognised when a money subsidy is thus openly paid.

Other hindrances to trade. There are other ways than those just described by which the natural course of trade is hindered. The protective system, erroneous as it may be, is, at any rate, intended to encourage national manufactures; but in some countries new enterprises are actually and sometimes even directly discouraged by the laws and customs which prevail; and especially so when such enterprises are introduced by **Jealousy of foreigners.** foreigners. Very often, opposition arises from jealousy—none the less because it may be unavowed—on the part of the ruling class *See page 51, Part I.* concerning all undertakings introduced by foreigners, or which tend **Tenure of land.** to alter existing methods. In some cases, peculiar laws or customs concerning the tenure of land hinder the exploration for minerals or their economical treatment. In other cases, taxes directed specially at the new enterprise may be imposed without warning; or, where permission to utilise the products of the country depends upon the will of some sovereign ruler, a sudden or new decree may have the effect of confiscating the capital already embarked. Even in countries where there is a semblance of justice in these respects, government **Government interference.** interference often acts as a restraint. For instance, the right to trade or manufacture, sometimes depends on licenses or concessions, the **Concessions.** price for which is—all or part—a source of revenue to dishonest *See Chaps. II. III. Part I.* officials or persons of influence. The price thus paid for what may really be a mere permission to benefit the country, loads the undertaking from the commencement, and leaves still the risk of competition when another permission is bought; while, on the other **Monopolies.** hand, if not only permission, but monopoly is granted, the community *See page 27, Part I.* is taxed. There are of course undertakings—such as tramways, **Sometimes necessary.** waterworks, gasworks—which must to some extent be monopolies, and in the profit of which it is right that the community should share; *See page 33, Part I.* though it would generally be better if such a share lay in the conveniences afforded, low tariffs, or the reversion of the property after

a term of years, rather than in a money contribution to the public revenue. In some cases, trade is much hindered by vexatious restrictions, even though these may be of a petty kind. For instance, onerous laws as to master and workmen, undue responsibility on the master's part for accidents, taxes on materials or on revenue may exist —these terms being often secured by heavy sureties or money-deposits. Hindrances such as these may harm the community for the advantage of a few; and though experience has proved that, in regard to industrial undertakings, a government acts best by interfering as little as possible, in England there are laws which are none the less in restraint of trade because enacted for the public good. The Mines Regulations Acts, the Compensation for Accidents Act, laws as to hours of labour for children or for the enforcement of education, all, in the first instance, increase the expenses of production. But it cannot be doubted that such laws, wisely applied, will so increase the comfort or intelligence of the workmen as to fully balance the apparent loss.

Restraining laws.

Philanthropic restraint. *See also page 2, Part I*

Ultimately advantageous.

Obstacles sometimes arise from the method rather than from the amount of taxation. Thus, manufacturers are greatly hindered in some countries by taxes so imposed as to require, to prevent evasion, constant inspection and regulation of processes. In England, the numerous taxes of this kind which formerly existed, and which required a costly and complex administration, have been almost all abolished, with a gain to the community far outweighing the taxes sacrificed. Paper and glass afford conspicuous instances, for these industries, when relieved from the inspection and interference of the excise officers, become greatly extended, and better, more numerous, and cheaper commodities are manufactured. And, although excise limitations on malt, beer, and spirits still exist, they are recognised as evils which are minimised by the nature of the articles taxed, and by that need of revenue which forbids their abolition.

Vexatious excise laws.

Instances.

Engineering factories in countries where such industries are new, and especially factories in seaports, are generally first established for doing repairs, which must be performed locally; and there are few foreign cities where Englishmen are not concerned in such trades. Railways, docks, gasworks and other undertakings which are necessarily localised, as well as the steam-ships frequenting the port, require constantly the services of the engineering trades; and factories whose primary purpose is to satisfy such wants, find employment also in new work on a small scale. When the natural resources of material

Factories first established for repairs.

Growth of factories. and an industrious people are available, manufactures may so increase as at last to entirely supersede the necessity for importation. Trade so established on a natural basis is more likely to prosper than that dependent on subsidies or protection. Manufactures are encouraged in some countries by the granting of a monopoly to whoever will inaugurate a new industry; and a justification of such monopolies may to some extent be based on the same grounds as justify the patent rights granted to inventors; for to the community an entirely new industry has somewhat of this character. But though expediency may in some cases excuse the granting of monopolies to encourage the investment of capital, trades so fostered are seldom of real advantage, and the evils of the system outweigh the supposed benefits. Government aid may be granted also by guaranteeing for a few years a revenue to some new industry which is obviously needed, but which, because of its novelty, may not without some such guarantee tempt capitalists to venture. But, as already stated, that legislation is of the best kind which, avoiding all positive interference, is directed only to the removal of obstacles, thus giving greater freedom for enterprise.

Exclusive rights granted.

Government aid.

Obstacles removed. *See page 25, Part I.*

Climate. *Climate* has to be considered in certain trades, as extreme heat or cold or moisture may render difficult or expensive or unprofitable, processes carried on successfully elsewhere. An iron or steel industry situated in a country where the hours of labour are lessened by seasons of extreme heat is obviously at a disadvantage with others not so hindered. On the other hand, in countries subject to intense frost, all operations depending on a water supply or the flow of water through pipes are liable to stoppage. Extremes of climate tell injuriously where workmen are brought from a distance into surroundings to which they are unaccustomed. As climate largely determines the kind of buildings and the provision which may be necessary for heating, lighting, and ventilating, a factory should be designed to meet the exigencies of the seasons, such as the heat, cold, rain, and winds that prevail. Any precautions which are usual in the locality to meet these conditions should be investigated, and, if expedient, imitated. Too often it does not occur to those on the site who are familiar with these circumstances to describe them to the engineers at a distance whose aid they may seek for designs and projects. Sometimes the climate may render artificial warming or special ventilating arrangements necessary, and in all matters of this kind the comfort of the workmen is in the true interests of the master.

May hinder manufacture.

Or injure workmen.

Buildings must be suitably designed.

Precautions taken.

In a climate where extremes of temperature or—as in England—frequent rains hinder out-of-door work, the covering in of open spaces may prove a remunerative investment of capital. Workmen will obviously work better when protected from the weather; and the saving must not be measured merely by the hours saved in which work would otherwise be hindered, but by much indirect gain. The current charges of a factory continue, even though the work be stopped; and after a stoppage, much time is often lost in starting again. If all the men do not return together, groups of men dependent on each other may be rendered useless by the absence of one or two. Outlay may be better bestowed to avoid such losses than on showy buildings or expensive offices. Unless in a retail trade, purchasers are little influenced by such supposed attractions, and simple offices suitable for their immediate purpose are in better keeping with the object of a manufactory. The design for a factory obviously depends largely on the building materials available in the locality, and the reasons for or against importing particular kinds should be carefully considered.

Out-of-door work hindered.

Advantages of proper shelter.

Showy buildings to be avoided.

Building materials.

See page 70, Part I.

The choice of *Locality* depends mainly on the contiguity to material, on the cost of transport, on the abundance of labour, and on contiguity to the consumer. Taxation and other public burdens have also to be considered; for these vary in different localities, and in some cases it is cheaper to establish a factory outside a certain district or town. The importance of contiguity to suitable materials depends on their weight or bulk, the cost of carriage, and the proportion which this bears to the whole cost of production. Thus, in the ruder operations of the iron trade, such as smelting, if the coal and ore do not lie together, the necessity for carrying one or both long distances to the furnaces might entirely forbid the trade, unless the carriage was, by means of water communication, cheap, or unless still greater difficulties intervened to prevent a delivery of iron from abroad.

Choice of locality.

Contiguity to materials.

See IRON, *Chap. XVIII.*

Materials must be of the kind exactly suitable, the application of scientific processes to manufacture which is constantly going on prescribing standards of comparison which cannot be ignored. Thus, in the manufacture of steel, not only coal and iron ore are needed, but special kinds of each; and even in countries where coal and iron abound, some part of the materials may have to be brought from long distances. All the countries which make steel by the modern processes have to seek far and wide for suitable ore, and the cost of

Materials must be of proper kind.

Steel an example.

See STEEL, *Chap. XVIII.*

carriage from the mines of Spain and other Mediterranean countries which furnish supplies to Europe and America is an important item in the cost of production.

Contiguity to material sometimes unimportant.

In trades where the material bears a small proportion to the total cost, distance matters little, if other circumstances are suitable; and a maker of cutlery and firearms is not—other circumstances being favourable—weighted much even if the iron and steel are imported from a distant country. The folly of taxing raw or half-advanced materials is recognised generally, even in countries where the fallacies of protection prevail.

Facility of transport.

Roads and bridges.

See in Part I. page 25, also BRIDGES.

Facility of transport is an important incident in most manufactures, not only for the raw material, but for the finished products; and as has just been seen, an industry otherwise feasible and desirable may, for want of such facilities, be entirely hindered. Except in the most primitive countries, where each district provides for its own wants, inter-communication is a necessity; and next to the maintenance of law and order, it is the first duty of a government to promote the construction of roads, bridges, and harbours. Instances are numerous of countries highly favoured by nature, having abundant minerals, fuel, and water-power, which are entirely useless for want of means of communication. When such countries border on the sea, manufactured goods which might be produced at home are brought from foreign countries and delivered within a short distance of the inaccessible native products. A government will do more real good to a country in removing such disabilities than by giving to native industries so hindered the artificial stimulus of protective duties on imports, a course which perpetuates the very evils which need a cure.

Water carriage cheapest.

See EXPORT, *page* 36.

See LOCOMOTIVES.

Canals.

Sometimes costly.

Water carriage is the cheapest and best, and navigable rivers are one of the greatest natural advantages in any country. Goods once embarked may be carried long distances for a tithe of the cost of road or railway carriage; and in the case of bulky, heavy, or fragile goods, the risks of carriage are generally less. For however much competition or other causes may reduce rates of railway freight, the bare cost of haulage must at least be paid. Even for an inland trade, canals can compete with railways in the cheapness of carriage, except where a very prompt delivery is of great importance. Canals can, however, seldom be constructed profitably except in level countries, for numerous locks not only involve large capital expenditure, but increase the cost of maintenance and working.

It is obvious, that for any but a local trade, factories should

be situated on lines of communication; and even where the manufactured goods are for local use only, the raw materials may have to be brought from a distance. The cost of carriage by land or water depends greatly on there being goods to carry in both directions, this being one of the numerous advantages of the free exchange of commodities. Thus, when iron ore and coal are 100 miles apart, the vessels or railway waggons taking ore to the coal may bring back coal to the ore. Trades utterly dissimilar may assist each other in this way, and, indeed, allow an otherwise impossible profit by reducing the cost of carriage.

Factories on main routes.

Return cargoes cheapen carriage.

See page 36.

See page 35.

Cartage may be saved by building a factory immediately on the railway, canal, or river which serves for transport; but while, for engineers or others dealing in heavy merchandise or materials, the point is of importance, in other cases the convenience offered should not be over-estimated and allowed too great a weight against the opposing advantages of another site. The proportion which the expense of cartage bears to the total cost of production and delivery differs, of course, with the nature of the trade, and while an ironmaker and a bridge-builder may economise by bringing in coal and iron, and loading up goods directly on to a railway truck, canal-boat, or ship, a manufacturer of machine-tools or small steam-engines, if there be the general advantages of the railway or canal carriage into the town or district, might find no sufficient inducements in a saving of cartage to draw him from an otherwise desirable site. A railway siding at a factory often enables a manufacturer to load and pack his goods more carefully or systematically than would be feasible at a common railway station, and, in the case of heavy goods, to utilise special cranes of the factory which do not exist at the station. Railway companies, however, do not always allow a reduction of charges corresponding to the duties of which they may be so relieved.

Cartage.

Railway sidings save cartage.

Advantageous in heavy trades.

But may be over-estimated.

Facilities for loading.

See CRANES.

For a foreign trade, contiguity to the sea and means of transport are of great importance; and it is to advantages in this respect, as well as to the possession of iron, coal, and skilled labour, that England owes her success against foreign rivals. Frequent transfer and transhipment are not only expensive, but involve risk of damage; the minor charges in these respects often exceeding the actual cost of transport. The vast outlay on docks, quays, sidings, cranes, and other facilities for shipment, reduces greatly the expenses of the manufacturer and the merchant. These advantages, to the countries which possess them, do much in the competition of traders to balance even superior natural resources in other countries.

Carriage by sea.

See SHIPMENT, *page 35.*

See HARBOURS, *page 96, Part I.*

Contiguity to the consumer may outweigh other advantages.

Contiguity to the consumer is sometimes of greater importance than contiguous material, for the convenience to the purchaser of ready conference with the manufacturer, of speedy delivery, and the facilities afforded by local factories for after repairs, may outweigh the mere saving in money which purchasing from the more distant manufacturer might allow. This is illustrated by the example of agricultural implements, the manufacture of which is carried on in districts not generally favourable to engineering trades, but amongst a population of farmers who purchase. So, also, shipbuilding may prosper at commercial ports not so well favoured in regard to contiguous materials as other and more remote places. In great cities, or centres of population, trades may generally be found which, though not favoured by circumstances generally deemed essential, have grown up to satisfy a local want.

Second-hand trades.

Trade in second-hand or waste material generally flourishes in a large city; and among the trades which thus arise that of rolling high-quality iron from scrap-iron may be instanced.

Labour.

Labour is a primary necessity in all manufactures, and in the engineering trades, skilled workmen may generally be best obtained in localities where there is a congregation of similar or kindred trades,

Workmen congregate at trade centres.

as numerous factories create a good labour market, and induce workmen to seek employment there. Such a congregation of factories also brings purchasers to the locality. New countries are at a disadvantage in this respect.

Contiguity to subsidiary trades.

Contiguity to subsidiary trades is sometimes of more consequence than at first appears. Thus if a Birmingham gun-factory, a Sheffield steel-works, or a Nottingham lace-mill, could be transported with all its workmen to a country where materials were plentiful and a demand brisk for the commodities, they might fail to compete with imported goods for want of the preliminary trades which perform cheaply, because exclusively, the earlier processes with the raw material; for want of the adjunct or contributory trades for repairs and renewals; and for want of the various minor purveyors who surround the numerous similar factories in England, but which a single factory could not alone support. In other words, this subdivision of labour requires a large trade and a busy population: thus industries needing such contributory trades are difficult to transplant.

Contiguity to fuel or power.

See Chap. XVII.

See COAL.

Contiguity to fuel or to power may be absolutely necessary to allow of competition with rivals similarly favoured. Fuel for steam boilers may be of such primary importance as to be classed as a material of manufacture; and factories which have been established in or near a

forest because of the fuel it affords become worthless when the timber is exhausted. The *kind* of fuel which can be obtained in the locality is one of the numerous circumstances which determine its suitability for a factory; the importance of this condition depending of course on the nature of the trade contemplated. In an iron-foundry or rolling-mill, an abundant supply of fuel is of consequence; while in a steel-works, the kind, quite as much as the abundance, is a condition of success. The proper choice or design of boilers and furnaces depends not only on whether coal, coke, or wood, is to be used, but partly also on the particular sort.

The kind of fuel.

See ENGINES *and* BOILERS.

See STEEL.

Water is necessary to most trades, quantity being important in some cases, as for washing ores or making paper; quality in others, as for brewing, bleaching, and dyeing; while in others, the pressure from elevated reservoirs or from rapid streams, is valuable as power. The durability of steam boilers depends greatly on the kind of water which is used; and if it be very hard, or impregnated strongly with lime, the iron plates deteriorate much more rapidly than with good water. But it is possible to minimise the evil by a special construction of boiler, and therefore the facts should be known to the engineer who designs the machinery. In some cases, in the vicinity of the sea-shore, or of tidal rivers, only salt water is obtainable, and the arrangements usual with marine boilers become necessary. Water is needed for condensing-engines, and if the supply be limited, it may be expedient to store that discharged from the air-pump in a pond or tank, and to re-use it; while if only salt water be obtainable, surface-condensers are preferable. A supply of pure and cool drinking water for the workmen not only adds to their comfort, but tends to their sobriety. On the source of the supply the necessity for wells and pumps depends; on the abundance of the supply and the liability to drought or scarcity, the kind, number, and position of storage tanks. If the water is to be derived from public works, the head or force in the mains, the price and terms at which the water is sold, and any limitation to its free use, should be fully known and considered at the outset. The position of contiguous water mains, or other existing source of supply, should be ascertained and delineated on the building plans.

Water supply.

Quantity and quality.

See WATER WORKS *in Part I.*

Special boilers may be necessary.

Water for condensing-engines.

Potable water.

Supply and storage.

See PUMPS *and* TANKS.

The supply of *Gas* or other material for lighting should be described; and if there be no public gas supply it may be expedient to construct gas-works, and the arrangement of these must be embodied in the design. Advantage may be taken of the motive-power of a

Gas for lighting.

See GAS WORKS *in Part I.*

Power utilised for lighting. factory to apply other systems of lighting. Thus, the apparatus for an electric light may be set in motion; or the blast provided for melting-furnaces or smiths' fires may be applied to crude-oil lamps, this latter system affording a cheap and brilliant light for out-door operations.

Choice of site. The choice of a *Site* must be determined partly by local circumstances, and partly by the nature of the trade; and great care is requisite not to exaggerate too much the importance of one set of **Value of land.** incidents to the exclusion of the others. The value of land for a factory depends, of course, on its position in regard to a town and to **Freeholds.** lines of communication, on the soil, and on the tenure. A freehold is esteemed everywhere; and there are few countries where the peculiar conditions which are common in England in connection with leases, titles, and restricting covenants, apply with equal force. The **Measure of price.** agricultural value is generally the primary measure of price, and land of low value in this respect may frequently be obtained cheaply for **Suitability for foundations.** building on. Suitability of the soil for foundations is a matter whose consequence depends on the kind of buildings and on the nature of the trade. The condition of the site in these respects should be known to the designer, and whether it is already cleared, levelled, or **Drainage.** *See also in Part I.* drained. If the site is drained, or if there be any system of drainage established in the neighbourhood, information concerning it should be furnished, and noted on the plan. A loose soil may involve great cost in foundations, a damp soil may be unsuitable for furnaces, **Expenses of adaptation.** boilers, or foundry pits, and need expensive adaptation. On the other hand, considerable expenses for adaptation may be justified by special causes; as, for instance, where the advantages of a river frontage may warrant considerable outlay for pile-driving or cofferdams for em- **Objections to undrained soil.** bankments or wharfs. The placing of a factory on marshy or undrained soil, or on a river bank, may render certain operations of manufacture difficult or impossible. Certain kinds of castings require pits below the ground level, and if these are liable to be flooded, expensive iron lining to the pits may become necessary.

Workmen's houses A site otherwise desirable may be rendered useless for lack of workmen's houses; and if these have to be built specially, the capital **Prices of food and clothing.** expenditure becomes greatly increased. It is expedient sometimes in the case of certain trades to choose a locality remote from a town, so that labour, or materials, or power, or other necessary commodities may be obtained cheaply; but skilled workmen not unfrequently dislike factories remote from large towns, and prefer places where

comforts and amusements are more abundant. An expenditure for workmen's houses often proves a profitable investment of capital; but if the houses depend entirely on the new industry for tenants, a heavy pledge for its continuance is added to the general risks. Not only houses, but cheap food and clothing reduce the cost of labour, and these advantages are best obtained by allowing freedom of commerce to the various purveyors who will arise to supply a demand. Too often, taxes on commodities hinder manufacturers by so enhancing the cost of subsistence as to render high wages unavoidable.

Capital spent on houses.

Cost of living reduced by free trade.

See also page 53.

In establishing a factory, one of the primary considerations which must be kept in view throughout the design is the *Capital outlay* and the proportion it will bear to the probable revenue. Many of the most profitable industries have grown up piecemeal from very small beginnings, every fresh extension being justified by a pressing need and guided by a preceding experience. A manufacture so established is, however, often greatly hindered by the want of order and arrangement in the various parts or processes; and a succession of additions and attempted improvements sometimes culminate in an entire rebuilding of the factory. It is not unnatural, therefore, that capitalists, in establishing a new factory, estimate their profits highly because of the improved plans they are adopting, and on the fact that they benefit by an accumulated experience available for their information. The ingenuity which suggests all these arrangements may, however, be a cause of positive loss instead of profit. So much money may be laid out on railway-sidings, special machinery, and other facilities, that, unless a large output can be maintained, the load of capital swamps the entire undertaking. For in the desire to have every arrangement perfect, there is risk of incurring an expenditure which may really prove unremunerative, even though the outlay has been for labour-saving processes. Factories so established may eventually repay those who can afford to wait; but without a large trade the burden of capital, especially if some of it be borrowed, is a frequent cause of failure. Ultimately the profit is reaped by those who take advantage of the failure to buy the factory for much less than it has cost; and instances are not uncommon of a second or even a third change of ownership before the capital can be brought down to a sum on which the earnings will allow a profit. Cases of this sort mostly arise when a period of prosperous trade encourages the extension of factories, which attain completion only when a re-

Capital outlay.

Want of order in old factories.

Expenses of re-adaptation.

Improvements may cause loss instead of profit.

Excessive capital a cause of failure.

Change of ownership becomes necessary.

Rate of interest on money. action has taken place and trade has become dull. The current rate of interest is the primary standard by which the sufficiency of profit must be measured, the greater rate of interest or profit necessary to induce an investment of capital in manufactures being determined by the risks and trouble of the particular trade in question. In new **Low interest advantageous.** countries the current rate of interest is much higher than in England, where spare capital is abundant for those who have security to offer; and this high rate of interest for money is as much a disadvantage in international competition as dearness of material, labour, or any other necessary commodity.

Order of procedure. In preparing the plan of a factory, the *Order of procedure* in the processes of manufacture, and provision for after-extension, are two circumstances not always easily reconciled. The first may be con- **Laying out of factory.** sidered as of the more immediate importance. In dealing with heavy materials which have to be treated in many departments, the cost of manufacture and the general economy of the factory greatly depend on the arrangement of the various workshops, so that the proper **Sequence of operations.** sequence of operations may be observed. It is thus desirable to **Haulage and lifting.** avoid, not only unnecessary carriage, but unnecessary lifting also. Goods from factories on high ground can be despatched down-hill to *See* CRANES *and* LOCOMOTIVES. a railway or port very cheaply, while if on low ground, the material may be brought down-hill to the factory. In favourable cases, the empty waggons can be drawn up by the descending loaded waggons. In some factories it is sought to bring in the materials on an upper story, and to let them descend through the various workshops and processes to the ground, so that the materials may be taken in at the higher level and carted out at the basement. Hoisting may, however, be so cheaply and expeditiously performed by the various modern appliances, that too much importance should not be given to plans for avoiding it; and the same consideration applies in esti- **Ground floor and upper stories.** mating the advantages of a two or many-storied factory, as compared with those of one where all the processes are carried on on a ground floor. Although in special cases, such as an iron-foundry or smelting-works, a ground floor is alone suitable, there are often positive **Advantages of upper floor.** advantages in working on an upper floor. Light and air may be better obtained; the workmen are less disturbed by other operations, and may be kept under better control; and there is also the obvious saving in the area of land required. Travelling-cranes and hoists, as **Modern facilities.** usually applied in England, allow of plans and workshop arrangements of a kind formerly impracticable or expensive. On the other

hand, where land is abundant, and there appear advantages for the trade in question in working upon the ground floor, the cost of handling and moving materials and goods must not be measured by the distance, but by the facilities obtainable for carriage. Tramways allow heavy or bulky articles to be moved easily and cheaply; and, unless there be some special advantages obtainable by connecting to lines of railway outside, narrow gauges are best. From 10 inches to 15 inches gauge will suffice for a warehouse, and 18 inches to 30 inches gauge for an engineer's factory, these latter dimensions allowing the use of locomotives. For the purposes of a factory, such a line may even be laid with advantage between the rails of a standard-gauge railway already established for outside communication. On the whole, however, for convenience in a factory, hoisting is cheaper than horizontal carriage, but in both the cost depends, not merely on the distance traversed, or even on the bulk or weight of the articles, but on the number of times they have to be handled or attached to the moving power.

Tramways.

Narrow gauges.

See LITTLE RAILWAYS.

Comparative cost of hoisting and haulage.

Subdivision of trades.

The design of a factory depends, of course, on the nature and extent of the proposed industry. The preparation of the raw material, and the after manufacture of it into articles of utility by other persons who purchase it, are a main division which prevails in almost all manufacturing trades. Thus, for instance, the smelting of iron and the rolling of plate-iron are generally maintained as trades quite separate from those of the founder or bridge-builder. But even where by general rule or custom such a separation of work prevails, there is often a tendency towards a combination of the two manufactures; and though the expediency of such a combination must obviously be determined by the merits of each particular case, there are certain main principles which—in varying degree—apply to almost all cases. The subject has to be considered from the point of view of the manufacturers of the finished article, who wish to produce also the material which they have hitherto purchased; and from another side in the interest of those who have confined their attention to the production of such material, and who wish to enter upon the final manufacture also.

Primary trades.

Tendency towards combination of trades.

Supposed saving of intermediaries.

In the struggle of competition, and in the desire to economise at each stage of production, the manufacturer may be led to undertake the earlier processes with the idea of saving an intermediate profit which may allow a sale of the finished commodity at lower prices than rivals can afford; but this is, to a great extent, fallacious, for

the capital employed in a really distinct function should earn its own profit; and it can hardly be expected that the earlier processes will be cheapened under inexperienced or deputed management. Sometimes, even where the need and the cost of the additional capital are fully recognised, a larger or more easily earned total profit is the object still in view. The vicissitudes, risks, and difficulties of an accustomed trade are perfectly well known; but the earnings of another's trade are more apparent than the dangers or the drawbacks which belong to it. The maker of the raw material, which has to be sold at exactly regulated market rates, sees that the finished commodity is sold at prices not so strictly defined, and which, in ignorance of the actual conditions of manufacture, he may consider very profitable; while the second maker, who has generally more varied difficulties to encounter in his proper business than the first from whom he buys his material, is tempted to enter upon a trade which appears to be simple, easy and profitable. A maker of the first material is sometimes reluctantly compelled to enter upon the secondary or finished trade to find an outlet for his products; but if these cannot otherwise be disposed of, the fact generally implies a slack or fluctuating demand for the finished commodity also. One of the best justifications for establishing a factory to furnish the material which it would be more usual to purchase, is where there are actual circumstances, such as distance, or lack of competitive sellers, rendering a regular supply doubtful; or where it is important to have materials of high or peculiar quality which cannot otherwise be ensured.

Additional trade requires additional capital.

New risks undertaken.

Mistaken hope of profit.

Combined trades sometimes necessary.

Disadvantages of combined trades in dull times.

There is often the disadvantage in the dependence of manufactures upon each other, that in dull times, the trade in the final products may not be sufficient to absorb the materials prepared for it; and if, to dispose of these, an outside sale is attempted, successful competition with established traders is doubtful. Again, the trade in finished products requiring a variety of material, may often be greatly hampered by the necessity of purchasing from one source, and may be at a disadvantage with those which are free to select from numerous purveyors, and which can make available a cheap supply from any quarter.

Subordinate trade in refuse products.

Sometimes a subordinate trade is established for the utilisation of refuse products, which would otherwise be entirely wasted; but it would often be preferable if possible, to induce or even assist others to establish such a trade as a separate undertaking. In any case,

where two or more trades are carried on together, the costs of the different departments should be so recorded as to show distinctly the burden and profit of each; for if only the general result be known, those branches of the business may be encouraged or extended in which actual loss is accruing.

Separate accounts should be kept.

The tendency of trades is to subdivision into specialties. Thus, for use in an engineering factory, not only the material, but all castings and heavy forgings, may be purchased, and neither a foundry nor a steam-hammer be established. Although possibly some profit may be lost in this way, a less amount of capital is needed for plant and appliances; and a manufacturer with limited means, but with a knowledge of his own particular trade, may wisely confine himself to it; at any rate, till he has acquired means and experience to go farther.

Tendency towards specialties.

The arrangement of a factory depends also on the particular kind or class of commodities to be manufactured. Thus in an engineering works, the kind of machinery to be made (which will itself be determined by the wants of the local and other trades employing it), or, in an iron foundry, the kind, size, and weight of the castings, will do much to determine the kind of buildings, the thickness of walls, the strength of cranes, the width of doors, and other points of importance. In most cases there are accustomed measures of quantity by which the extent or capacity of a factory can be described. Thus, in an iron foundry, there is the tonnage of castings of a specified kind per week; in a bridge-building factory the annual weight of structures; in a locomotive or marine-engine factory the number of engines of a certain size that can be erected at the same time, and the total capacity of output per year. This information should be furnished to whoever is consulted about any part of the factory, for the kind and quantity being thus stated, the various processes and departments of manufacture, with the suitable apparatus and machinery, can be designed in due proportion.

Suitability of a factory for its purpose.

Accustomed measures of output.

Where a large trade is expected, it is generally sought, in the arrangement of the site and buildings, to provide for future extensions, but it is generally prudent to confine the first expenditure to what will be immediately remunerative. Sometimes it may be sufficient merely to take care in the design that nothing shall hinder such an after-extension; whilst in other cases it may be expedient even from the first to provide for certain departments or processes of manufacture in excess of the immediate demand upon them. Thus in an

Extensions anticipated and provided for.

Ample space provided. engineering workshop, space for a foundry may be provided or enclosed, although its immediate use may not be contemplated; or an **Cranes made strong enough.** erecting-shop may be made large enough, and the overhead crane strong enough, for a heavier class of goods than are at first to be made; for while stronger machine-tools may be easily purchased when the need arises, the alteration of the premises might prove dif- **Extra land enclosed.** ficult or expensive. If land be cheap, it may be expedient to purchase at the outset sufficient for the probable extensions, although sometimes the cheaper plan may be feasible of acquiring with one plot of land the right of purchase for a certain number of years of adjoining plots. If purchased, the surplus portion may either be let **Workshops built but not furnished.** out to tenants on short terms till wanted or fenced in. Sometimes it is deemed expedient to carry further the preparations for an extended trade. The buildings may be erected, but not furnished with plant. Thus in an engineering factory, shop-space for additional work-benches or machines may be provided at the outset, and utilised **Walls and columns made ready for after attachments.** merely as storage-room. In such a case, the walls and columns may with advantage be made of suitable form and strength for carrying lines of shafting; columns turned for the ready attachment afterwards of cranes or drilling-machines; and in various other ways preparations made which add little to the immediate cost, but which will save much expenditure in the future.

Extensions need caution. In deciding upon the expediency of any extension which a sudden increase of trade may suggest, or on the purchase of new plant or machinery for manufacturing some new class of goods for which a demand has arisen, the probability of permanency in the new demand **Invested capital irrecoverable.** must be carefully considered; for capital once invested in such a way is not easily recovered, and a too hasty expenditure to meet an expected augmentation of trade is one of the most frequent causes of **Foresight to be observed.** disaster. Foresight is necessary in the arrangement of the buildings to ensure symmetry and due accord between the various processes; and to this end, the plans should be decided upon only after they have been considered with reference to each department of manufac- **Unity of design.** ture. If it be attempted to prepare the plans piecemeal—for instance, to design the building and then consider what machinery shall be used and where it shall be placed, and then only to arrange the order **Instances.** of procedure—trouble and loss are almost certain to occur. For example, in an engineering factory it may be found that the buttresses of walls do not accord with the positions of shafting brackets; that roof beams are not strong enough or properly spaced for shafting

hangers; that the light does not enter in the most advantageous way; that doors are inconveniently placed or too small; that the columns are suited only for their primary purpose of supporting the roof, and that they require, for want of suitable brackets or projections, uncouth additions to accommodate cranes, shafting, or drilling-machines. The positions of important machines, and especially of engines and boilers which may require excavations or foundations, should be considered before the building is commenced.

See SHAFTING, *Chap. XVII.*

Provision for extending.

Where parallel blocks of workshops are erected, land may be left for extending any or all of the blocks endways. Lines of shafting or pipes in the original workshops may be made of size or transmission-capacity sufficient for the ultimate needs.

Designer needs full information.

In discussing the scheme of a new factory, a plan of the proposed site, with neighbouring roads, railways, and canals marked upon it, should be considered; as the shape of the site, its levels, and position in regard to these circumstances, determine the arrangement ot the buildings. The direction from which materials will be brought, that in which the finished commodity will be taken out, and the means of conveyance, should also all be borne in mind.

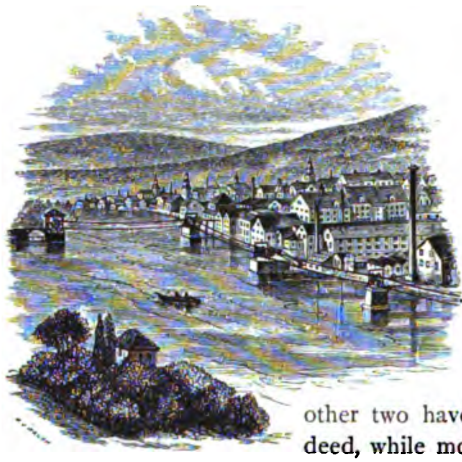
Similar rules necessary in all manufacturing trades.

The foregoing remarks have been directed mainly to the establishment of engineering works, and a due regard to the points alluded to is necessary to the proper designing of a factory. But engineers are concerned in the establishment of almost all kinds of factories, where also considerations of a similar kind arise. A proper scheme can only be propounded and a design made, on the basis of full information on every point; and though the varieties of purpose and circumstance in different trades are too many to be enumerated, the nature of the points to which attention is necessary, may to some extent be gathered from those which have been given in this chapter for one important industry.

[*See also* TRANSMISSION OF POWER: STEAM-ENGINES: CRANES: MACHINE-TOOLS: ROOFS AND BUILDINGS.]

CHAPTER XVII.

THE TRANSMISSION OF POWER. STEAM. WATER. COMPRESSED AIR. ELECTRICITY. CONNECTING-RODS. SHAFTING. BELTING. WIRE ROPE.



THE generation or development, the transmission, and the application of power are three distinct processes which have occupied engineers in all ages. Of these three, however, the intermediate link — the transmission of power— has not received so much attention as the other two have, or as it deserves.

Transmission systems neglected.

Indeed, while motors of every conceivable kind have been the subject of innumerable inventions, and while machine-tools and labour-saving processes have been applied to all branches of the arts and manufactures, the transmission of power from the motor to the machine has, either because it is less interesting, or because it has appeared to be of less importance, been comparatively neglected. Not only is there frequently an unnecessary loss in transmission, but natural sources of power have been entirely neglected because they are situated in remote or inconvenient places, the means really available for transmitting such forces having been insufficiently appreciated. More attention is, however, now being directed to the various transmission systems, both in Europe and America.

Different systems of transmission.

In comparing the respective advantages of the different means ot transmitting power, the circumstances to which regard must be had,

and which will, indeed, determine the choice to be made, are various. First, there is the nature, situation, and amount of the motive power, with which one system of transmission rather than another may accord; secondly, there is the distance to be traversed and the obstacles that intervene, which may render certain methods of transmission unsuitable or impossible; thirdly, the power may either have to be transmitted in the gross or distributed; and fourthly, there is the nature, situation, and extent of the machine or process to which the power is to be ultimately applied, and to which one system of transmission may lend itself more readily than another. **Choice, how determined.**

Before attempting to apply these considerations, the various methods of transmitting power may be briefly enumerated as follows:— **List of methods.**

Fuel is the only form in which even potential force can be transmitted long distances, *i.e.*, from one country to another. **Fuel.** *See page 72.*

Steam, as the most convenient form of developed heat-force, finds its best application in the place where it is generated; but if need be, it can be conveyed considerable distances. **Steam.** *See page 73.*

Water is used for transmitting power in two distinct ways: one, where from a high-level source it conveys the force of gravity; and another, where as a transmitter only, it conveys force given to it by some other motor. **Water.** *See page 75.*

Compressed Air is used for transmitting force produced by some original or secondary motor. It is available for considerable distances, but it is costly, and finds its chief application where the power-receiving machine is so situated as to render other and more usual methods inconvenient. **Compressed air.** *See page 86.*

Electricity, though capable of conveying force, has been hitherto rarely employed to transmit more than the minute energy necessary for telegraph signalling; but in new and cheaper forms it is becoming available for transmitting much greater forces, under circumstances and in situations where all other means of transmission would be impossible. **Electricity.** *See page 95.*

Connecting-rods are used for conveying power to considerable distances, and for many simple purposes, where merely a reciprocating, and not a circular, motion is required, they are cheap and effective. **Connecting-rods.** *See page 99.*

Shafting is seldom used for transmitting gross power for more than short distances, but for distributing power it is more often employed than any other means. **Shafting.** *See page 102.*

Belting, though it may be regarded merely as an adjunct to shafting, needs separate consideration as a transmitter, for it is used, not **Belting.** *See page 105.*

only for distributing power, but—to an increasing extent—for transmitting gross power.

Wire rope. *See page 111.*

Wire Rope is used, not only for distributing power, but for transmitting power for considerable distances in the gross. Since the comparatively recent dates at which wire-ropes were introduced, their uses have been greatly extended; and there are many situations for which they are better suited than any other means.

Transmission by fuel.

Stored-up force.

Collieries in Great Britain.

See COAL, *Chap.* XVIII.

See page 124.

See STEAM-ENGINES.

Fuel, as the portable embodiment of potential heat-force, in that it allows the energy stored up at one place to be utilised for giving motion to machines at a distance, may be legitimately classed among transmitters. So conveniently are the collieries of Great Britain situated for shipment of the coal, and so great are the facilities for sea-carriage, that coal may be transported with advantage to distant countries as a source of power. So cheaply is this effected, that railway traffic in India or South America can be worked almost as cheaply as in England by means of coal carried 10,000 miles. Thus, to transmit force to the best advantage, it is obvious that high-quality coal should be chosen, and of a kind that deteriorates the least in stowage and transit, so as best to repay the expenses of carriage common to all qualities. The work of the steam-engine may be included as the last part in the transmitting process, and a steam-engine that consumes only 3 lbs. of coal per horse-power per hour can be worked more cheaply with coal carried half round the world than can a steam-engine in the vicinity of a colliery, where—perhaps because of its abundance—10 lbs. of coal per hour are consumed.

Peat fuel.

Not profitable.

Unless transmuted at site.

Peat, as a less concentrated form of fuel, can seldom compete with coal, even in the immediate vicinity of the place where it is found, except where freedom from some of the ingredients found in coal is essential for a special purpose, the numerous plans that have been attempted for compressing or otherwise preparing it not having rendered it valuable enough to bear the expenses of preparation and carriage. If, however, the new methods of transmitting power to a distance prove successful, peat-beds may, like collieries, oil-wells, waterfalls, or other local sources of power, be transmuted into other kinds of force which can be profitably conveyed.

Coal-gas fuel.

Gas engines. *See Chap. XIX.*

Coal-gas is a transmitter of heat-force useful in many situations where furnaces and steam-boilers would be inconvenient. Gas-engines may even be profitably employed for giving power to dynamo-

electric machines, for electric lighting, or for power, if transmission by electricity be expedient. The original heat-force in the coal is thus transmuted four times: into gas, mechanical force, electricity, and once more into mechanical force, before it is applied to the ultimate purpose in view. *See* ELECTRICITY, *page* 95.

Zinc and other metals having a potential heat-force, which may be developed by combustion, might be included in the present category; but, except that zinc is alluded to under the head of electric transmission, such substances do not come within the scope of the present article. **Heat force in zinc.** *See page* 95.

The transmission of power by *Steam* is, in the great majority of cases, confined to the few feet distance between a boiler and the cylinder of a steam-engine; and it is obviously advantageous for many reasons thus to utilise the power as near to the generator as possible. But there are, occasionally, situations where this contiguity is unattainable; and experience shows that steam can be effectively conveyed long distances. At mines, for instance, boilers above ground supply pumping and other engines more than 1,000 feet below; and though the loss by condensation in transit is a difficulty which may render other systems of transmission preferable, this can be met to a large extent. The envelopment of steam-pipes in felt or other non-conductors of heat, is effective in proportion to the care with which it is performed; and, for long distances, elaborate precautions are sometimes taken, by which steam may be conducted 2,000 feet with a diminution of not more than 5 lbs. pressure. The preservation of ice from melting or of hot food from cooling when protected in a similar way, are analogous cases. Steam for the warming of buildings is frequently conveyed long distances in pipes; but though this may afford an example of transmission, it is, of course, the very purpose of such pipes to give out, and not to retain, the heat. **Transmission by steam.** **Short distance best.** **But long distance feasible.** **As in deep mines.** **Condensation.** **How prevented.** **Loss minimised.**

It often happens in a factory that small steam-engines are required in situations where steam-boilers would be inconvenient, or where their presence would increase greatly the rate of fire insurance. Moreover, a special attendant who would not be required for an engine is needed for a boiler. Machine-tools, whose distance from the main shafting of a factory or whose great size renders transmission of power by shafting inconvenient, are often fitted with a separate steam-engine which may, under certain circumstances, be advantageously supplied with steam from a distance; especially where the machines **Engines needed, but boilers inconvenient.** **As in machine-tools.** *See* MACHINE-TOOLS.

are only occasionally worked, and where, therefore, the maintenance of pressure in a contiguous boiler or the time occupied in raising steam would be wasteful. But the intermittent nature of the service required, which may render the maintenance of heat or high pressure in a contiguous boiler inconvenient, is, on the other hand, a direct cause of loss when steam is brought from a distance. For, however well the pipes may be enveloped, they become in a short time, when the connection with the boiler is cut off, as cold as the surrounding atmosphere; and therefore, though the pipes, when once thoroughly heated, may conduct the steam with but little loss, there must necessarily be considerable condensation, and therefore unremunerative consumption of fuel, each time the steam is admitted to them after a stoppage.

Intermittent service.

Pipes become cold.

The distance to which steam may be effectively conveyed in pipes is a subject on which there is some controversy among engineers, arising probably from the different experiences on which opinions are based; for though, as above stated, steam may be conducted 2,000 feet with a loss of only 5 lbs. pressure, a much greater waste, even in shorter distances, occurs in the majority of cases, owing to the insufficiency of the precautions taken. There are instances in England and elsewhere of one large boiler supplying steam to numerous tenants of adjoining workshops, whose rent to the proprietor for the room they occupy is made to include payment for steam also. This distribution of steam for power purposes is, however, generally limited to moderate distances, in one block or closely contiguous blocks of buildings. So effectual, however, is the plan of enveloping the pipes in non-conducting material, when properly applied, that it has been proposed to distribute heat and power in towns to distances as great as a mile from one central group of boilers. The difficulties which are likely to arise are, however, so great as to render the general adoption of such a system unlikely. Steam-pipes should be kept under cover, and be protected from risk of damage or interference; and it is, of course, necessary to provide suitable traps and outlets for condensed steam, and expansion joints; though the latter need not be so frequent if there happen to be numerous bends in the piping which allow of some play or yielding. If situated on private property, troughs or trenches below ground may serve, if there be no convenient roof shelter; but if the pipes would have to cross streets or pass along public highways, the attendant risks or inconveniences generally forbid their use. With regard, therefore, to the trans-

Limit of distance for transmission by steam.

Sale of steam to users from central boiler.

Distribution of heat and power in towns.

Difficulties.

Precautions.

mission of steam considerable distances in towns for distribution and sale to users, although such a system might be feasible where streets are made in the modern manner (as in London and elsewhere), with subways specially contrived for water, gas, and other pipes, the local difficulties and conflict of authorities in towns not so provided would almost certainly be prohibitory.

Street subways for pipes.

Long distances in towns impracticable.

The expediency of transmitting power by steam depends a good deal on the manner in which the power is to be utilised. If a rotary motion is desired, an engine will generally be more effectually worked by steam than by water, if a boiler be available within 1,000 feet and there be no obstacles in the way of the steam-pipes; for, though water is often used for transmitting power long distances, it is, if applied to rotary engines, generally confined to those of small capacity. If, however, power is required for direct-acting machines, such as cranes, presses, punching-machines, or riveting-machines, then water would compare more favourably with transmitted steam. In large engineering factories, it is becoming the custom to have a separate steam-engine for each of several machine shops, or at the end of each line of main shafting, instead of driving everything from one large engine; so that while, on the one hand, if an accident happen to the engine, only one workshop or department is affected; on the other, if one or more departments be idle, long lines of shafting or the large steam-engine may not have to work unnecessarily. It may be convenient to use such numerous engines where numerous boilers would be inconvenient; and long lines of steam-piping from a central boiler might, in such cases, be usefully applied.

Application of steam power.

Steam best for rotary engines.

See WATER-ENGINES, *Chap. XIX.*

See HYDRAULIC POWER, *page 82.*

Numerous small engines instead of one large engine.

See SHAFTING, *page 102.*

The modern tendency towards higher pressure of steam than formerly allows more margin for a reduction in pressure during transit; but the unremunerative consumption of fuel which a reduction implies is none the less. There is always the inconvenience, that the loss in transit reduces the dryness of the steam, and increases the liability to priming. The superheating of steam by a second process after it leaves the boiler is directed towards this evil, and neutralises some of the effects of long transit. The question of conveying steam long distances is simplified if, by care in the arrangements, it can be resolved into one merely of expenditure of fuel, against which can be set the conveniences which in any particular case are obtained.

High-pressure steam.

Superheating.

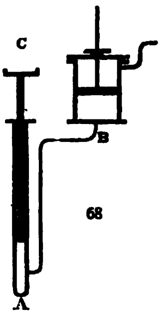
See Chap. XIX.

Power can be transmitted, or stored, or concentrated, or distributed by *Water;* and in many cases more effectively and cheaply so, than

Transmission by water.

Water columns or rods. **Power transmitted from steam cylinder.**

by any other means; some or all of these separate functions being combined according to the purpose in view. For the mere transmission of power, water may be regarded as a long column or rod, which, if force be applied to it at one end, will give out a similar force at the other. Thus, if it be desired to convey the force exerted by steam on a piston, to another piston 100 yards or 1,000 yards distant, a pipe laid underground from one to the other will perform this effectually. For instance, there may be in or about a factory a hoist too remote from the nearest steam-engine, or the requirements may be too intermittent to utilise its force economically by means of shafting or steam-pipe. The hoist used for lifting pig-iron and fuel to a cupola-furnace is an example. If a ram or piston-rod working in a cylinder, A, be placed beneath the platform of the hoist, C, and this cylinder be connected by a pipe to a steam cylinder, B, conveniently placed in a boiler-house at a distance, and the pipe filled with water, the platform of the hoist may be made to rise by admitting steam above the piston in the boiler-house; and the water in the pipe being pushed forward, in its turn pushes up the ram of the hoist and holds it in position as long as the steam pressure is maintained. By allowing the steam to escape, the hoist falls by its own weight, the water flowing backwards or forwards at each of these operations. Water, though it may be thus compared to a column or rod, has the great advantage over them that it can be conducted by tortuous routes without requiring moving mechanism of any kind. The simple method above described was in use in England about 1855 (Fernie's patent), and since that time "hydraulic rods," "water bars," or "water spears," as they are called in different districts, have been substituted in several instances, both in England and abroad, for the long reciprocating rods so often used for transmitting power in mines.



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Method of working. **Advantages afforded.** **Water instead of connecting-rods at mines.**

Fallacies about water-power. **Elucidated.** **Weight of a column of water.**

There is practically no limit to the distance which power can be transmitted by water, but as a misapprehension frequently arises in regard to hydraulic apparatus, even among those acquainted with other mechanical processes,—such hydraulic machines being sometimes regarded as generators or creators of power, or as capable of evading natural laws by producing great results without either a corresponding exertion or a consumption of already existing force—it may not be superfluous to elucidate shortly the principles involved. A column of water of 1 square inch sectional area weighs nearly ½ lb. for each foot in height, a column 100 feet high weighing 43½ lbs.; and if such a column of water were applied to a pair of scales, or to

the end of a lever, it would have neither more nor less effect than the same weight of iron, or sand, or quicksilver. The force or power which can be obtained from any head of water, is simply the product of its weight per foot (which depends as above said, on the sectional area of the conduit), multiplied by the number of feet in height; and if there be also taken into account, as in a waterfall or rapid, the abundance of the supply or speed of flow, the number of foot-pound units, affording a measure of horse-power will be arrived at. While, however, a large reservoir or supply pipe will serve for large or numerous machines, it is fallacious to suppose that the power of any one water motor of given size will be increased by enlarging the reservoir or pipe. Such an enlargement would have no more effect than would the increase of boiler and steam pipe on the power of a steam-engine with a cylinder of given dimensions. It is the head or height of column and not the area of the supply which determines the power, as will be further elucidated presently in the description of the Bramah press. It is, however, desirable and usual to have the supply pipes of hydraulic machines of ample size so as to minimize the loss by friction.

Abundance of supply.

See HORSE-POWER *page* 160.

Power depends on height, not area.

See page 81.

The extreme fluidity of water, which enables it to pass by tortuous routes into the narrowest or smallest place, allows the weight or force of gravity which a column or head of water expresses, to be applied in a variety of ways, and to a degree which is impossible by any other means. Accordingly, engines contrived with cylinder and piston similar to those in steam-engines can be worked by water; but a natural head of water is seldom attainable, and to produce it artificially a steam or other motor for pumping up the water would be required, which, in most cases, would be better applied directly to the ultimate purpose in view. The want of elasticity in water also renders it less suitable than steam for giving rapid piston motion, and water pistons are used only at slow speeds. Water engines, therefore, are seldom used except where there is a natural head of water, or one—as in connection with a town supply—provided for other purposes; or where it is desired to utilise power from a distance, or where for some secondary reason it is undesirable to use steam.

Water conveyed by tortuous routes.

Water engines with moving pistons worked by pumped-up water.

Direct steam-power generally preferred.

By means of water the smallest forces may be so accumulated and transmitted as to bring them, with the aid of other transmission-systems, into practical use. An instance of such a combination would be afforded where, some considerable mechanical force being needed and neither water-power nor fuel being obtainable, wind was

Accumulation of power by water.

Wind power utilised by water.

the only kind of force available. Windmills may be usefully applied to pumping-up water; and, as is often seen in Holland, they work without attention, whatever be the direction in which the wind is blowing. By such a means, therefore, water could be pumped up to an elevated reservoir; small pumps worked nearly continuously, accumulating a large quantity. The water from the reservoir could be brought down in pipes and applied through the medium of a turbine or hydraulic engine, and thence by means of compressed-air, high-pressure water, wire-rope, shafting, belting or connecting-rods to the ultimate object in view. Probably by no other means could the fluctuating action of the wind be so well transmuted, accumulated, and applied.

Stored in reservoirs.

Transmitted by various means.

The water power in town mains.

The main pipes by which water is supplied to towns may be and frequently are utilised for transmitting power, the force of course depending on the height of the reservoir from which the water flows. There are cases in which water-engines, cranes, and other machines are worked even so far as twenty miles from the reservoir, without the intervention of any other apparatus; and the advantages of a system by which power may be transmitted over hills and valleys, and even across rivers, by simple pipes, are obvious. Whether it be remunerative to use water which has been pumped up by steam-power to the reservoir, depends on the cost of fuel for the engines, on the facilities for obtaining power in some other way along the line of pipes, and on other local circumstances. A more favourable case occurs where there is a high-level lake or other natural source, or where a waterfall or rapid stream is available for working the pumps without any expenditure for fuel. In such cases, power necessarily localised can be conveyed to a distance, and profitably distributed. The rapid rivers in Switzerland have in this way been utilised by means of wheels or turbines, which pump up water to high-level reservoirs, from whence it descends in pipes, and is supplied for working small water-engines in factories or workshops. There are numerous trades where moderate power is alone required, and where small water-engines of from ½ to 5-horse power are very useful, as they can be worked at any hour at the will of the user, who pays only according to the water consumed, as measured and registered by a meter on the engine. In Zurich, for instance, power so provided is sold at a rate of 5d. per horse-power per hour, which is less than ¾d. for 100 foot-tons of power. Such a charge, though high if compared with the cost of obtaining power from a steam-

Conveyed long distances.

Points to be considered.

Favourable cases.

Natural power.

River power in Switzerland used for pumping.

Small water-engines.

See Chap. XIX.

Cost per H.P. in Zurich.

engine by the expenditure of fuel, is cheap if the convenience of having power always at hand be also reckoned. Moreover, it must be taken into account, in estimating the cost, that as the tariff is according to quantity and not according to time only, the net power utilised has alone to be paid for. Not only, however, is the water from the public mains available in the manner above described, but it is used for portable engines also, water-engines on wheeled carriages moving from place to place, being instantaneously connected by hose to a street hydrant, the exhaust-water being allowed to flow into the gutter. In this way, sawing-engines perambulate the town for sawing wood for fuel; and during building operations, small water-engines, attached to winches or hoists, are fixed at the foot of the scaffolding for hoisting building materials, the waste water being useful for mortar-mixing or other purposes.

Compared with cost of steam.

Water power for portable engines.

Power taken from street hydrants.

Small water-engines are driven by water from the public mains in many English towns. In Newcastle-on-Tyne, for instance, small motors, hoists, and cranes are worked in this way, the pressure varying from 60 to 90 lbs. per square inch, according to the locality, the abstraction of water for other purposes, and leakage. In Newcastle, however, the system compares disadvantageously with the more effective accumulator pressure which is there so widely adopted.

Power from street mains in England.

Accumulator system preferred.

See page 82.

The amount of power which the public mains afford depends, of course, upon the height of the reservoir which supplies them, and the consequent pressure of the water; but in arranging the water supply of a town, an engineer will be guided by consideration of the pressure which will take the water to the top of the highest houses, or which will afford sufficient force for the jet of a fire-engine, and not that which will permit the conveyance of power for general purposes. A head of water of 50 feet, giving a pressure of 22 lbs. per inch, is the least which would render water-engines profitable; for, with a small pressure, the friction of the machine, leakage, and other disturbing incidents, tell with great effect. A higher pressure is therefore much to be preferred; but it is seldom that a head of more than 300 feet is provided in the public mains. A higher pressure is inconvenient for domestic water-supply, as special fittings become necessary, and the risk of loss by leakage or waste is increased. So far do these considerations prevail, that where the reservoir is more than 200 feet above the town, or where there is great difference of level in different districts, it is usual to divide the town into different zones of altitude, and to provide service-reservoirs at the moderate height considered

Pressure in main, how determined.

See WATER-WORKS *in Part I.*

See FIRE-ENGINES, *Chap. XX.*

Low pressure unprofitable.

Limit of pressure in street mains.

Zones of altitude

See page 174. Part I.

Power often wasted. necessary for each. Where, however, the source or first reservoir is at a greater height than that needed for the domestic supply, and if there be surplus or spare water, it is inexpedient to waste the store of power which gravity affords; and if there be trades which can utilise it, a special main, from the higher level, for water-motors and fire-extinction would be generally advantageous. Pipes strong enough to convey water of 300 feet pressure cost little or no more than those for 100 feet, and even pipes for a head of 500 feet are scarcely more expensive.

See PIPES, *Chap. XX.*

Selling price of water. The selling price of water depends on various circumstances, principally on the abundance of the supply and the cost of obtaining and distributing it. Degrees of softness for washing or manufacturing, purity for domestic use, and pressure for fire-extinction, are the incidents on which the value of water depends; and it is obviously the last-named by which the value of a supply for power-machines is determined. Water is generally sold to large consumers by meter, 4d. and 2s. per 1,000 gallons being, with few exceptions, the extreme rates which prevail in England; and, unless the capital expenditure has been very large, it will generally be found that even the minimum affords a sufficient return. Where water is scarce, the authorities may refuse to sell it as power; and even if the supply be liable to stoppage in dry seasons, this application of it may, in a manufacturing community, be rendered useless. But where an abundant rainfall affords a more than sufficient supply for most seasons of the year, the expediency of constructing storage reservoirs is worth consideration. Water is used most profitably in those trades—such as paper-making and dyeing—where the exhaust-water from the motor can be utilised for a second purpose. Although a head of more than 200 feet is seldom afforded by town mains, and a natural head of more than 500 feet is generally unattainable, even by special pipes, except in mountainous countries, forces which such a height expresses are much below those which are best suited to hydraulic machines other than prime-movers. And as, with a low pressure, large quantities of water would be required to afford great power, this application of gravity-force is limited in its application. But the use of water merely as a transmitter of power derived from some other motor needs separate consideration. The low pressure may, however, by a simple apparatus, be multiplied for special machines; but it can then only be conveniently applied for a direct action and a short stroke.

Value, how determined. **Water sold by meter.** *See* WATER-WORKS, *Part I.* **Seasons of drought.** **Storage.** **Exhaust-water utilised.** **Natural head of water not enough.** *See page 83.*

Bramah press. In a description of power-transmission by water, the Bramah press

almost necessarily finds a place, as it was the first in a series of inventions by which the peculiar properties of water were rendered available. Just as water finds its level by the natural law of gravity, so will water confined in a close vessel, or in a series of vessels communicating by pipes, press equally in all directions; and if to such a close vessel or series of vessels a vertical pipe be attached and filled with water to the top, there will be a pressure on every square inch on all the sides of the vessel of nearly ½ lb. for each foot of height, or, for example, if the height be 1,000 feet, the pressure per inch will be 435 lbs. The diameter or sectional area of the pipe or column is of no consequence; it may be 1 inch or 1 foot with equal effect: although, of course, if the sides of the vessel or any movable ram or piston within it begin to yield, so as to give out this concentrated pressure, the smaller pipe will, if not kept replenished, be exhausted sooner than would the larger one. As it is practically impossible, except in mountainous countries (where sometimes water from an elevated source is brought down to the valley for scouring out the soil under the appellation of hydraulic mining, or for other purposes), to obtain a column of water 1,000 feet high, the same effect is artificially produced by loading a plunger or ram or piston so that it presses upon the water in the small pipe connected with the vessel in which the power is required. Bramah effected this by a small plunger-pump, and the power was concentrated in the larger vessel—a cylinder with a moving piston—with which the pump was connected by a pipe. This is the principle of the hydraulic press, which is seldom now called a Bramah press; and such machines are generally used for giving out great power for a small distance, as for expressing oil from seeds, packing bales of cotton or hay, or for working "lifting-jacks." For such purposes, pressures of from 2,000 lbs. to 6,000 lbs. per inch are most usual. The apparent paradox thus presented, of small force transformed into great force, is the cause of the misapprehension of hydraulic machines before alluded to. But the apparent multiplication of power—as it is sometimes erroneously considered—should rather be termed a transmutation, for no more foot-pounds of energy are given out than are applied. Thus, if the piston of a hydraulic cylinder have an area 100 times as large as the pump-plunger which supplies it, the force produced, though 100 times as great, will be exhausted when the piston has moved only $\frac{1}{100}$ of the distance traversed by the plunger; or, stated in another way, 2,240 foot-pounds on a pump-plunger will give out only 1 foot-ton on the

Laws of pressure.

See also page 77.

High column of water unattainable.

Pressure produced artificially.

By plunger-pump.

See PUMPS, *Chap. XX.*

Hydraulic presses, how applied.

Usual pressure.

Paradox explained.

See page 76.

Power transmuted not multiplied.

Concentration of force.

piston. Thus, it is easy in a hydraulic lifting-jack, where perhaps it may be desired to lift 10 tons 1 inch high, to exert by a succession of strokes by a lever on a plunger ¼ inch diameter, the 1,866 foot-pounds which is the equivalent. Bramah was hindered for a long

Difficulties.

time in bringing his invention to success by the difficulty of making his piston or ram watertight when moving under great pressure; for the ordinary hemp packing used in steam-cylinders, where the pressure is much less, was quite inadequate; and he succeeded, through the

Leather packing.

happy discovery made by another engineer, that leather packing, arranged in a peculiar way, would allow freedom of motion and yet prevent the passing or escape of water.

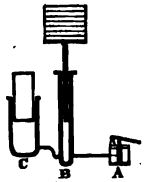
Hydraulic pressure slow.

Hydraulic pressure was, for many years after Bramah's time, confined to presses where great force was only required to be concentrated slowly; the process of pumping to accumulate the small units

Unless powerful pumps used.

of force, occupying too long a time for general purposes, unless steam-engines and pumps of great magnitude were provided, the expense of

Accumulator system.



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which would outweigh the benefits sought. Armstrong's invention of the accumulator, however, overcame this difficulty and opened out a wide field for the application of power concentrated and transmitted by water. By the accumulator system, the pumps, A, instead of forcing water directly into a press cylinder, C, are applied to the forcing up of a loaded plunger, B, which, in pressing upon the water pumped against it, acts as a substitute for an elevated reservoir. The accumulator is connected also with the machine in which the force is to be

Stored-up power.

utilised, and when communication is open between them, pressure from the falling accumulator is instantaneously conveyed to the machine, and so far as its own stored-up energy will allow, completes

How applied.

the desired operation. If for instance, a certain operation lasting half a minute, has to be performed twenty times per hour, which would require to effect it in that short time a pumping-engine of 60-horse power, an engine of 10-horse power continuously employed in raising an accumulator, will store up the total energy required; or if only ten times per hour, an engine of 6-horse power will suffice. Or,

Force always kept ready.

if instead of services requiring great power, numerous small operations have to be performed at irregular intervals, the accumulator has always in readiness a force which can be instantaneously applied. The ad-

Even at long distance from pumps.

ditional convenience that the power can be conveyed long distances —for the accumulator and pumping-engine may be situated a mile or more from the power-receiving machine—greatly increases the usefulness of the system, as is exemplified by its application to the work-

ing of cranes, the opening of dock-gates, and the lifting of swing-bridges. The accumulator pressure which has been found most convenient for these services is about 700 lbs. per square inch; equal to a head of water 1,600 feet high; this pressure affording sufficient power through the medium of moderate-sized machines, and yet not requiring various special arrangements which pressures above 1,000 lbs. would involve.

Usual pressure employed.

See CRANES.

It has been proposed to combine the accumulator system with that adopted in Switzerland, of conducting high-pressure water through the public streets for sale as power. If the public water-supply in any town were already available as power, it would probably not be expedient to establish another set of pipes for this purpose, but if the public supply were not sufficient, the high-pressure which an accumulator service affords, would offer great conveniences in the smaller and cheaper water-engines required, as compared with such engines worked with low-pressure water. This application of the accumulator system has been already tried with success in Hull, where water of 600 lbs. pressure is transmitted in pipes, the power being sold to users at annual rates varying according to the quantity bought, and equivalent to from 1d. to 1½d. for every 100 foot-tons.

Accumulator system for public supply.

Advantages afforded.

Example at Hull.

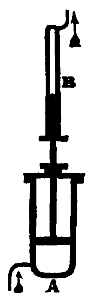
Prices charged.

For working machine-tools, and more especially portable or movable machine-tools, according to Tweddell's system (principally applied to riveting) where a great concentration of force is necessary, a higher pressure than that usual with the Armstrong apparatus is needed to allow power-receiving machines of moderate size to be used; and accumulators exerting a pressure of 1,500 lbs. to 2,000 lbs. per inch are generally employed. For many of the purposes for which hydraulic machines are used, pressures of from 3,000 to 8,000 lbs. are customary; but as power and not speed is the object in view, the pressure is generally obtained directly from the pumps without the intervention of an accumulator. Where a low-pressure system is established for general purposes, the force can be concentrated for special machines; the wonderful facilities which water affords, allowing this to be done very simply. A pressure of 1,000 lbs. per square inch in one cylinder, A, on a piston having an area of 100 square inches, transmitted by the piston rod to a second cylinder, B, called an intensifier, or differential-accumulator (the piston-rod acting as a plunger) having only 20 inches area, will be multiplied five times, and water of 5,000 lbs. pressure per square inch can then be conveyed to the machine that needs it. Of course the supply, though thus greater in intensity,

High pressure for machine-tools.

See RIVETING MACHINES.

Direct pressure from pumps.



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Force intensified.

will be only one-fifth in quantity of that in the first cylinder, but for such operations as punching iron or for giving a final squeeze of a few inches to a bale, power and not distance is the object in view.

Non-compressibility of water a disadvantage.

The non-compressibility of water, by which many of the more important operations of hydraulic machines are rendered possible, and which allows pressure applied to one end of a column of water or hydraulic rod, to be given out at the other and distant end, with but little diminution, is a cause of inconvenience in some respects. Directly the pressure from the original source—gravity, force-pumps or other—is withdrawn, the water is powerless, for it has no self-contained or elastic force of its own like steam or compressed air. In a steam-engine or compressed-air engine, the supply may be so cut off or adjusted that the steam or air will expand till its pressure is but little greater than that of the surrounding atmosphere; and according as the work to be performed is great or small, the supply is cut off early or late, so that as little as possible of the force may be wasted; but in a hydraulic machine the pressure must be maintained to the end, and if applied to a less purpose than its maximum capacity, the balance of power is wasted. Thus, if a hydraulic-crane, capable of lifting 1 ton, is used for lifting 5 cwt., three-fourths of the power is wasted; while in a steam-crane, by cutting off the supply of steam at the proper moment, the expansive force can be more nearly proportioned to the end in view. Improvements have, however, been introduced into hydraulic machines, which to some extent meet this disadvantage. On the other hand, the non-compressibility of water allows a pressure, once given, to be maintained, provided the machine is in good order so as to prevent leakage.

Water has no elastic force like steam or compressed air.

See CRANES.

Pressure can be maintained.

Limit of water pressure.

In theory, the pressure which may be conveyed by water, would seem unlimited, but in practice, the limit is reached at a point much below that at which metals would be actually compressed. Hydraulic machines in all cases require good material and workmanship, but where the pressure exceeds 6,000 lbs. to the inch, the liability to derangement of parts rapidly increases; and although by using specially-made machines, higher pressures than 6,000 lbs. per inch may be attained, the risk of packing-leathers failing, or of cylinders, pumps, and valves bursting, increases. The cylinders of hydraulic machines subject to these high pressures are necessarily made of great strength, but little or nothing is gained by increasing the thickness of metal beyond 4 inches, as the metal becomes coarse and allows the water to pass through. The area exposed, and the consequent total strain

Bursting of machines.

Thick cylinders.

upon the cylinder, increase with the diameter, and therefore small cylinders can endure greater pressure per inch than large ones. For this reason, where great force is needed, numerous small cylinders are employed instead of a single large one. Steel cylinders are frequently used for hydraulic presses, but though stronger than iron cylinders there is even more difficulty in making sound castings. Steel, compressed when in a semi-molten condition by Whitworth's modern invention, is the strongest material yet discovered. But to utilise a strong cylinder to the utmost, it is desirable to avoid as far as possible applying the maximum pressure to the valves, pumps, and other small parts most liable to derangement. This can be effected in a very simple way by the intensifier previously described, as a pipe may be taken directly from the high-pressure end of the apparatus to the press cylinder, without the intervention of valves of any kind; the pumps and regulating valves being all at the low-pressure end of the apparatus. This method has been used with good results for the final compression of cotton bales, where great density is desired. The great majority of hydraulic machines are, however, worked at moderate pressures, and are not subject to the above risks.

Steel cylinders.

Compressed steel.

See also page 154.

High pressure on valves avoided.

See page 83.

As in cotton presses.

One difficulty connected with the transmission of power by water is the risk of the pipes freezing up during frost. This may be prevented by keeping the water in circulation or, where the quantity is small and little is lost, by mixing glycerine or spirits with the water. Oil is under special circumstances and in small machines used instead of water: it works equally well and has the advantage of lubricating the parts with which it comes in contact.

Freezing of water.

Oil used instead.

In conclusion, it may be said summarily that power may be conveniently transmitted by water—

Opportunities for water transmission summarized.

(1) Where the power is needed at long or irregular intervals.

(2) Where the distance is too great for steam-pipes.

(3) Where power, centrally situated, is to be distributed to distances and places inconvenient for shafting.

(4) Where some of the water-power already provided for other purposes is available.

(5) Where very small forces can only be utilised by accumulating them—as is instanced by wind applied to the pumping water into a reservoir for use afterwards as hydraulic power.

See page 78.

(6) Where great power is to be concentrated, either for such purposes as the packing of bales or for application at different points, as in Tweddell's system of riveting.

See MACHINE-TOOLS.

Transmission by compressed air.

Compressed Air may be either used as a transmitter for giving out directly at one end of a tube the force applied to it at the other, or it may be used for storing up and transmitting concentrated forces. The pneumatic bell is an example of the first or simplest method—a slight compression of the air at one end of a tube giving out at the other a similar force. The column of air (like the "hydraulic rod" described under the head of water-transmission) may be compared to a connecting-rod, with the advantage over the solid rod, that the power may be transmitted by tortuous routes and for longer distances, without intermediate mechanism of any kind. Another instance of direct transmission of power by compressed air is afforded by the pneumatic "liquid-ejector," in which air, forced into a closed vessel and pressing upon the surface of the liquid, forces it up a discharge pipe. This method has, for instance, been applied to the lifting of sewage in low-lying districts. Apparatus of this kind is used instead of pumps sometimes at chemical works, for raising liquids or semi-liquids which would injuriously affect the parts of ordinary pumps. In sugar-refineries, also, the machine known as a "*Monte-jus*" is an application of the same principle. This method of forcing upwards by a surface-pressure is perhaps shown most clearly in subaqueous pier-sinking; for when it is desired in a submerged diving-bell or caissoon resting upon the ground, to raise the excavated mud or gravel, it is only necessary to establish by a vertical pipe open at top and bottom, communication with the free air above, and then, any loose substance heaped up round the lower orifice of the pipe will rush upwards; for the air-pressure from the pumps above which is sufficient to keep back the water from the bell, will force sand, mud, or gravel up the pipe.

(Margin notes: **Pneumatic bell a simple example.** **Air column or rod.** *See* HYDRAULIC RODS, *page 76.* **Pneumatic liquid-ejector.** **Used for sewage or chemicals.** **The Monte-jus.** **Raising of excavated mud from an air-caissoon.** *See* BRIDGE PIERS, *page 117, Part I.*)

Postal telegraph tubes.

The pneumatic tubes used in connection with the postal telegraphs afford another example of the simpler method; but in these tubes, the power, instead of being transmitted to a fixed apparatus, as in a pneumatic bell, is utilised for conveying objects from one end of the tube to the other. It has been found more convenient in large towns, to transmit messages in writing from the various receiving offices to the central station than by electric-wire signalling. Tubes of lead about 2½ inches internal diameter, encased in iron pipes, are laid beneath the foot pavements, and within these tubes cylindrical carriers or pellets of gutta-percha covered with drugget, containing written messages, are propelled by pneumatic pressure. The distance is seldom more than one mile, although this could be exceeded if neces-

(Margin notes: *See page 87, Part I.* **For transmitting written messages.** **Description of pipe.**)

sary. The system has hitherto been chiefly applied in London, Paris, Vienna, and Berlin; in the latter city, the tubes being utilised also for a special express postal service of letters, which, though less speedy than the electric telegraph, is quicker than the ordinary post. On a larger scale, the same system was a few years ago applied in London to the conveyance of large packages from a central office to one of the railway stations. In this case, the tube was of iron, in shape like a tunnel or horse-shoe, 4 feet high and 4 feet 6 inches wide, and within the tube, running upon rails, was a carrier or waggon, provided with a disc or shield, fitting with enough tightness to the tube to act as a piston. A pressure of 4 or 5 oz. per square inch on the piston was sufficient to propel the truck. The system worked successfully, but has not been extended as was expected; the want of concord and co-operation among the various local authorities, and difficulties connected with the laying of the tubes in the public streets, being the chief retarding causes. Atmospheric pressure was tried in the earlier days of railway working, as a substitute for steam in the propelling of trains, but was found to cost more and to be less effective.

Where used.

Pneumatic underground tramway in London.

Method of working.

Atmospheric railway.

The most important application of air for conveying power, is that by which force is first concentrated, and then conveyed to the power-receiving machine. By special machines known as air-compressors, to which power is applied from a steam-engine or other motor, air is compressed to a density considerably greater than that of the atmosphere; it can then be stored in close reservoirs or portable vessels, or conveyed long distances in pipes, and applied to motors or machines of various kinds very much in the same way as steam, for, like steam, it is by the expansion or the release of elastic force that the power is given out. Considerable loss of power is incurred in the compression of air and in its application; and it is obvious that there must be grave reasons to justify such a transmutation of already existing motive force: these will be presently referred to.

Concentrated air pressure.

Air compressors.

Air stored or conveyed in pipes.

Loss in process.

In the compression of air, much of the force applied is absorbed in the production of heat, which not only cannot be utilised, but increases the resistance, and if not counteracted, renders an unprofitably slow speed necessary; involving a larger proportion of piston leakage than would accompany a greater speed. The attention given to the subject, as the usefulness of compressed air became apparent, and the greater knowledge acquired of all the working parts, have led to improvements which have greatly lessened the heat and leakage, and the proportion of useful effect obtained from a given

Compression force wasted in heat.

Improvements in apparatus.

expenditure of power has been greatly increased. The exact proportion ranges from 10 to 80 per cent., according to various circumstances which will be presently referred to. The passage of the compressed air through pipes involves very little loss if the pipes are of sufficient diameter and properly jointed, and not too high a velocity is attempted; for though much air may be wasted by leakage through imperfect jointing, the friction of air in pipes is much less than that of water. For mere transmission of gross power in a direct line, the loss need not be more than 3 per cent. per mile (in some notable cases it has been less), and though the friction increases somewhat if numerous bends or regulating-valves occur at the places of distribution, the loss when it occurs, arises principally from leakage, which is preventible by proper care. Leakage of air is not so apparent as is the escape of steam, water, or gas, and therefore more watchfulness is necessary to detect it; but by applying soap and water to suspected places, the leakage will be evident from the bubbles. A further and more serious loss has to be incurred when the compressed air reaches the machine in which it is to be applied; for, like steam, compressed air cannot within the compass of an ordinary machine, be allowed space to expand to the atmospheric rarity which alone would enable it to give back all its accumulated force; but, after having bestowed its high pressure on the piston of the machine, it escapes, and so wastes the remainder of its force. Just, however, as high-pressure steam has been found profitable because of the margin for expansion which it affords, so high-pressure air—if the difficulties in providing it be overcome—would allow economy by expansive working. But the expansion of the air is attended with intense cold, and the freezing-up of the exhaust ports and other orifices, are contingencies which attend the use of compressed air expansively. (So intense is the cold that compressed air, if properly regulated, may be utilised for refrigerating, or even for freezing liquids; the cost of fuel for compressing the air having to be set against the cost of ice or chemicals in the more usual machines.) Not only, however, is it thus impossible to give to the machine all the power which was originally needed to compress the air, but the mechanism of the machine can only utilise, according to its kind and construction, from 60 per cent. to 80 per cent. of the force it receives. Or—to use the expression common in steam-engines—there is from 20 to 40 per cent. loss between the indicated and effective power. Assuming that ordinary care be used in the arrangement and use of the apparatus,

Little loss during transmission.

Loss from friction and leakage.

Leakage not always apparent.

Loss in application of air pressure.

Expansive force of air.

Expansion attended by intense cold.

Utilised for refrigerating.

Further loss in application.

See HORSE-POWER, *Chap. XIX.*

the final expression of force or work done in the machines usually worked by air pressure would be found, owing to the losses which occur in compression, transmission, and application above described, only to equal from 25 per cent. to 40 per cent. of the original power, *i.e.*, the power which would be needed once more to recompress the air which has been used.

Aggregate loss.

But the loss in working depends mainly on the purpose to which the compressed air is applied. For instance, applied as in the ejectors before referred to directly on the surface of a liquid to be lifted, or even if used for giving power to a slowly-moving pumping-engine, arrangements are possible for regulating the supply and expansion of the air which would not be feasible in a small, quickly-working rock-drill. In this respect, the conditions and the comparison to be made would much resemble those which apply when steam is used for such dissimilar purposes. It must be borne in mind, however, that loss is always incurred in the distribution and application of power, and it has to be seen in each case whether the conveniences obtained outweigh the loss. For instance, small steam-engines worked intermittently, are extremely useful and remunerative, even though they consume 10 lbs. or even 15 lbs. of coal per effective horse-power per hour, as against the 3 lbs. per hour which a large, well-managed, and constantly-working engine will consume. And, if such an economical steam-engine be applied to the compression of air, which is then distributed in various directions to numerous small machines, even the great loss above described will express only a consumption of 12 lbs. for each effective horse-power. This will still leave an enormous gain in favour of the compressed air as compared with the cost of hand-labour, or even with steam-power conveyed and distributed considerable distances by shafting and belting.

Loss varies with mode of using.

Instances.

See ROCK-DRILLS.

Convenience gained outweighs loss.

See STEAM-ENGINES, *Chap. XIX.*

Economy of fuel in compressing engine.

Air compared with shafting or belting.

See page 105.

From the above point of view, the transmission of power derived from some natural or gratuitous source, such as a waterfall or rapid, or from water pumped up by a windmill, affords a favourable opportunity for using compressed air, especially when transmission by water is unsuitable; and in many such cases where the power is abundant, the loss in transmutation which has been referred to is of little or no consequence. Water-power is often situated near mines or places where compressed air is needed; and such power, developed at its source by a water-wheel or turbine, may be cheaply conveyed for many miles in pipes. Notable instances of such transmission are afforded by the works of the Mount Cenis, St. Gothard, and Hoosac

Air compressed by water-power.

Cheap and useful for work in mines.

Examples in tunnels.

(Massachusetts) tunnels, where power has been transmitted from two to four miles by compressed air. In hilly countries having an abundant rainfall, much gravity force is wasted in the water which flows downwards to the sea, but which, by compressed air, might be utilised within a considerable range of distance. But the profitable application of this method depends much on the continuousness of the supply, and—if the supply be intermittent—on the facilities for storing the water and even on the possibility of storing the compressed air. Opportunities may even occur, in connection with the water-supply of towns, for the utilisation, through the medium of compressed air, of forces which are generally entirely wasted. Where water is brought from a source elevated more than 300 feet above a town, it is usual to reduce the pressure to that convenient for domestic supply, by storing it in service-reservoirs, at less altitude; and if the water flow idly into such reservoirs, a force of gravity is wasted, which could be utilised by passing the water through a turbine or other engine, and applying the power so produced to the compression of air; which could be conveyed to the town in pipes and distributed to users. As compared with the transmission by water, previously described, the use of air so compressed would be advantageous in cases where the water-supply was limited; since the quantity of water would not be diminished if used at an intermediate level, as it would be if used in water-engines at the level of the town; the exhaust water in the latter case being wasted. Even when a mine or factory is situated at the higher level where the water affords no power, yet—if the water be sufficiently abundant, and be conducted by piping to the valley, and the force it has then acquired be utilised for compressing air—the power can be brought back up the hill in an air-pipe (though with rather more loss than attends transmission on the level); the very small weight of the transmitting column of air as compared with the weight of the column of water, allowing this to be accomplished. Now that the advantages of air-transmission are becoming widely known, and air-compressors are better constructed, it is probable that these methods will be employed more extensively.

Gravity force of water utilised by compressed air. — *Storage of water or of compressed air.* — *Town water-works.* — *See page 174, Part I.* — *Gravity force wasted, might be utilised for air-compression.* — *Without lessening town supply.* — *Gravity force transmuted and brought uphill.* — *Improved methods probable in future.*

The transmission of power by compressed air finds its chief application in mining and tunnelling operations; in mining, for underground hauling-engines, pumps, and coal-getting machines; in tunnelling, for rock-drills and locomotives. The work of a rock-drill is performed by a rapid succession of blows, for which a highly-elastic force like steam or compressed air is well suited. Steam is generally

Air chiefly used in mines and tunnels. — *See* ROCK-DRILLS.

used where the drills work in an open quarry or cutting to which a boiler can be brought sufficiently near, and in a tunnel also, if within 20 feet of the open face; for in such situations the exhaust steam need cause no inconvenience. But steam is almost unendurable in mines and tunnels; water if used as power has generally to be pumped up again; while air besides conveying power, has the great advantage of ventilating and cooling the place where it is used. This would alone justify its use in mines, even if circumstances did not there forbid other methods. In tunnelling, where holes are drilled for inserting the blasting charge, the atmosphere is so foul after each explosion of gunpowder or dynamite that the workmen cannot enter sometimes for one or two hours. Where, however, the rock-drills are worked by compressed air, the atmosphere can be purified and cooled in a few minutes. In badly-ventilated mines, the air-compressors are often kept at work for ventilating purposes only; the air so applied having more local effect than that from ordinary ventilating fans. The air in deep or imperfectly-ventilated mines is often hot and oppressive, and the miners cannot work to advantage. In such circumstances, a supply of cool and dry air from the compressors will greatly increase their energy and capacity. In cases where air, compressed on the surface, is taken down into a deep mine, the weight of the column of compressed air (which is heavier than the outer air), and the expansive force added to the air by the higher temperature of the mine, not only compensates for the loss by friction, but renders the pressure at the place of discharge greater than that at the compressor. In some cases where compressed air has been introduced into a mine, it has even been applied to winding or pumping engines previously worked by steam; the boiler being utilised as an air-container or reservoir.

Where air is preferable to steam.

Air ventilates and cools.

Purifies mines after blasting.

Air compressors instead of fans.

Stimulates workmen.

Depth of mine increases pressure.

Substituted for steam in engines.

Compressed air is sometimes used for working portable riveting machines, to which the power may be conveyed considerable distances in pipes and flexible tubes. Compressed air is also used for working the brakes of railway trains, the power of the locomotive being utilised for compressing the air, which is then transmitted along the train in tubes to successive carriages, under each of which is fixed a container or store vessel for supplying as needed a cylinder with moving piston connected with the brake. The vacuum brake is an inversion of this plan, a pump on the engine exhausting the air in the pipes and brake cylinders, the pistons then being moved by the direct pressure of the atmosphere.

Air for portable riveting machines.

Railway brakes.

How applied.

Vacuum brake.

See HOT-AIR ENGINES, *Chap. XIX.*

The expansive force of compressed air may be increased by heating it, this being the method adopted in air-engine motors.

Compressed air in subaqueous work.

See DIVING-BELLS.

Compressed air is used in subaqueous operations for supplying air to a diver in helmet and dress, or to a rock-drill which the diver works; for the diving-bell; for the sinking of pier cylinders; for supplying submerged caissoons; and for raising sunken vessels; the air-pump or air-compressor in these cases being indispensable.

Air stored in portable vessels.

As in tram-cars and torpedoes.

See TRAM-CARS, *page 255, Part I.*

Compressed air has the advantage over either steam or water, that it is portable and can be conveyed in a detached vessel long distances from the source of power. It is in this way that compressed air can be utilised for propelling tram-cars, where steam and fire and smoke might be forbidden; or for continuous brakes on railway trains; or for submerged torpedo missiles; and if successful for such services, there is no reason why the same motive power should not be applied to the engines of launches or boats in harbour service, where a few hours' work only is needed; so as to avoid the nuisance of fire and smoke.

Air compared with pressure-water.

See page 84.

It is obvious that high-pressure water is useless in cases of this sort, for, having no self-contained elasticity or force, its power is at an end directly it begins to work, if communication with the source be cut off.

Difficulties.

One of the difficulties in working engines with compressed air stored in a detached container, arises from the continuous dilation which goes on as the air expands or diminishes; special arrangements being necessary to maintain in the machine a constant power like that which is afforded by the continually-replenished supply of steam from a boiler.

How overcome.

The difficulty is generally met by interposing what is called a diminishing or reducing valve between the air reservoir and the cylinder, so as to bring the air to a uniform pressure before it is applied, or by variable cut-off valves.

Compressors.

Air-compressors are of various kinds, and with the extension of this system of power-transmission, the manufacture of such apparatus has become a special branch of trade.

Made with and without motors.

Air-compressors are sometimes made separate from the motor and worked by toothed wheels or belting; or, like steam-pumps, are provided with one or more steam-cylinders to render them complete machines.

Examples.

The lever air-pump of the laboratory or the ordinary two or three-throw pump used for supplying submerged divers, were the forms of air-compressors first commonly known; and the latter arrangement of vertical pump-barrels and crank shaft is applied to large machines also.

Various kinds of compressors.

Horizontal machines are now more common, the piston-rod from the steam-cylinder being sometimes continued as the pump-rod of the air-

cylinder. Rocking-beam engines with the cylinder below one end of the beam and the air-cylinder at the other end, are sometimes employed; this form being most common in blowing-engines for supplying air to blast-furnaces. One cause of difference in air-compressors, is the variety of methods adopted by different manufacturers for overcoming the great heat which accompanies the act of compression; the heat tending to hinder the proper working of the machine. The simplest plan (adopted, for instance, in divers' pumps), is to place the working-barrels in a tank which is constantly kept supplied with cold water. Another plan is to have pump-cylinders with a double skin like the jacket of a steam-cylinder, the annular space being filled with water. Sometimes cold water is ejected into the cylinder while the compression is going on; in others, water is made to circulate within the piston. The boldest plan is that of interposing a layer of water in the pistons and valves, so that these no longer come directly into contact with the air; the layer on the piston being really in some cases a column of considerable length which receives the pressure of the plunger at one end and gives it to the air at the other. This plan, however, has the disadvantage of allowing only a slow piston-speed, and, moreover, the air becomes charged with moisture, which increases the risk previously alluded to of freezing at the exhaust of the air-driven machine. The "trunk" air-compressor, in which the ends of the cylinders are left open to the atmosphere, is probably the best that has yet been contrived. In it, the inflow of air is facilitated with advantage, and the heating reduced to a minimum.

Different methods of neutralising heat.

Air-pump placed in water-tank.

Or fitted with water jacket.

Intermediate layer of water.

Disadvantages.

Trunk compressor best.

Air-compressors for working by belt or gearing, and therefore without steam-cylinder, cost from £100 to £300, and, if fitted with steam-cylinder, about one-fourth more; the boilers necessary for machines of these sizes ranging from 5 to 25 horse-power. Air-compressors of this kind are suitable for working one or numerous rock-drills, and for pumping-engines of small size; but for permanent pumping-engines or work on a large scale, compressors complete with steam-cylinder and boilers cost from £1,000 to £2,000.

Prices of air-compressors.

With and without steam engine.

The measure usually adopted for stating the air-pressure, is that of the atmosphere; compression to two atmospheres (about 30 lbs. per inch) or three atmospheres denoting the density. But the effective or working pressure is one atmosphere less than the gross force so stated, as there must of course be deducted the ordinary pressure of the outer air which is opposed to an advancing piston (unless a

Pressure, how measured.

vacuum be artificially created) and, if working under water, a still greater resisting pressure. In blowing-engines for blast-furnaces, the pressure is generally from 3 lbs. to 5 lbs. per inch; the blast for a Bessemer steel-converter is about 30 lbs.; for small riveting machines 15 to 30 lbs.; for rock-drills and coal-getting machines 30 to 50 lbs.; and for air-brakes 50 to 70 lbs. Where compressed air has to be stored in a detached or portable vessel, as, for instance, for use in a tram-car, underground locomotive, or torpedo, much higher pressures are attained; from 500 to 2,000 lbs. per inch being usual limits for these purposes. Air-compressors and accessories of a special kind are then needed, which up to the present date (1880), are not adapted for supplying advantageously air of such density through pipes for long distances. The higher pressures are usually attained by a succession of operations: thus, if a pressure of 1,500 lbs. to the square inch be required, a first operation might compress the air into one-tenth of its ordinary volume, or to 150 lbs. to the inch, and a second compression again multiply the density ten times. For supplying divers either in the helmet or in the bell, the air-pressure is not regulated as in the rock-drill, by the force which it is necessary to give to a machine-tool, but has to be exactly proportioned to the depth or head or pressure of water to be overcome. A depth of 100 feet is seldom exceeded by the divers, and therefore an air-pressure of 50 lbs. is about the maximum; but the greater proportion of diving-work is done at depths less than 100 feet and therefore a proportionately lower pressure only is required. Diving-bells seldom are available at more than 70 feet, and for this maximum depth air of about 35 lbs. pressure is sufficient.

Pressure suited for various purposes.

High pressure.

How obtained.

Pressure for divers.

See DIVERS.

An ordinary portable engine will give power to a detached compressor by a belt from the flywheel; while, if the compressor be complete with steam-cylinder, the power may be obtained by a steam-pipe from the engine-boiler. The steam can be taken directly to the rock-drills so long as their situation allows it (though it is inexpedient to transmit steam through the air rubber tubing if it can be avoided); the compressed air being applied as intermediary only where the machine has advanced so far into the mine or tunnel as to render the use of steam inconvenient. The pipes for transmitting compressed air may be of cast iron for the principal mains, but for distribution, wrought iron tubing is preferable; while if the power-receiving machine be movable, vulcanised india-rubber becomes necessary. Where life is at stake, as in subaqueous work, it is of the greatest importance not

Steam for working compressors.

See PORTABLE ENGINES, *Chap. XIX.*

Air pipes and tubes.

to run any risk by using ill-made rubber tubing, and good tubing will safely withstand much higher pressure than that usual in air-transmission.

See DIVING APPARATUS.

Air system, how limited.

In comparing the respective merits of different transmission-systems it will be found that the difficulties which have limited the use of compressed air arise in the transmutation and application, and that the mere transmission is easily effected. The minimum of loss is obtainable by working at a low pressure; but as this involves cylinders of proportionately large diameter, the advantage afforded by this condition is limited. In this respect air-engines differ from steam-engines, in which heat force is most economically generated at a high pressure. In fixed air-engines there is not much difficulty in having large cylinders; and a pressure of 20 lbs. to 30 lbs. is not unusual; but in a portable machine like a rock-drill, where powerful and rapid strokes are generally wanted, the machine would be too heavy and cumbersome if made for low pressure. For conveying power a considerable distance, 70 lbs. per inch may be taken as the maximum of modern practice.

Low pressure minimises loss.

But requires large cylinders.

Pressure for long distances.

Transmission by electricity.

Electric force is in most cases evolved by the combustion of zinc in a galvanic battery; and for telegraph signalling—for which, in general, batteries are used—the very small power required and the simplicity of the system render such a use of zinc cheap and effective. But although electricians have long been aware that much greater power could be produced in this way, and transmitted by a conductor wire or rod, the cost of the process has forbidden its practical adoption. Zinc—owing to the incidents of smelting and preparation—is an expensive metal, and the cost of the zinc from which a certain amount of heat-force can be liberated during combustion is so enormously in excess of the cost incurred for fuel in other motors as to put it out of the field altogether. But the discovery of Faraday that electricity could be produced by an expenditure of mechanical force, and the application of this discovery by the Drs. Siemens and others, have presented the case in a new aspect with regard to the proportionate cost of electricity and fuel, and bid fair to bring the new system within the category of useful and economical power transmitters.

Electric force evolved from zinc.

Too expensive for general use.

Electricity from mechanical force.

Dynamo-electric machines.

If by a belt from the fly-wheel of a steam-engine, or by other means, force be applied to turn the cylinder of a dynamo-electric machine sufficient to overcome the resistance of electro magnets

Power transmuted and transmitted. placed in juxtaposition, the original energy of the motor is transmuted into electric force, which can be conveyed long distances by a conductor-wire or rod, and through the medium of a second electric machine, be given out again in mechanical force by a belt or gearing. The knowledge already (1880) available on the subject is chiefly the result of experiments made by the Drs. Siemens in England and Germany, and by other electricians on the Continent; and although the system has been applied more in connection with lighting than for power-transmission, the latter is really involved in the former. Street lighting by electricity, and the illumination of the vicinity of war ships, have exemplified to the public the new discovery, but the most conspicuous success has been obtained in lighthouses, of which those at the Lizard and the South Foreland are the immediate examples on the English coast. By means of a small steam-engine (one of about 3½-horse power, weighing 4 cwt., is used at the Lizard) in the vicinity of the beacon, a light is obtained in the lantern immensely more powerful and brilliant than that afforded by any other means, and at a lower cost per hour than that which previous systems permitted.

Applied to electric lighting.

For streets, ships, and lighthouses.

See LIGHTHOUSES.

Loss in process of transmutation. The loss in each process of transmutation is about 30 per cent. of the force employed; that is to say, at the giving the force and recovering it at the power-receiving end; but these losses, if compared with those in other systems of transmission, are not prohibitory. There need be no loss in the mere intermediate transmission of electric power, if conductor rods of sufficient capacity be employed; but if they are of insufficient size, some of the electric energy is developed into heat, which is wasted by radiation from the conductor; and, if the disproportion be excessive the rod would at last be fused. There must, of course, be special reasons to justify in any particular case the use of an intermediate process like that here described, instead of the direct application of the original motor. Just as in the case of compressed air or pumped-up water which are used for conveying power, a justification is found in the convenience afforded in certain situations for transmission or distribution. The total loss need not be greater than 60 per cent. (*i.e.*, 30 at each end) if rods of sufficient size be employed; but it is an incident of this system that the conductor to work under favourable conditions must be increased greatly in size or sectional area as the distance increases. But being thus increased, it is capable of transmitting a proportionately larger force, and therefore, while small powers could only be conveyed

Loss in transmission.

Only applicable where convenience outweighs loss.

Conductor rods increased in size as distance increases.

cheaply for short distances, greater forces which would repay the cost of a large conductor rod could—if the theory based on recent investigations proves correct—be transmitted long distances with advantage. Thus, for instance, to transmit 5-horse power a distance of half a mile, a copper conductor rod $\frac{5}{8}$ inch in diameter would be required; while for one mile the sectional area of the conductor must be doubled; and for five miles a diameter of nearly 2 inches would be required. But, as such a conductor of 2 inches in diameter could as well transmit 50-horse power for a distance of five miles, the conditions then become more favourable. Dr. C. W. Siemens considers that further investigation will show the feasibility of employing smaller conductors; and carrying his theory to a logical conclusion, is of opinion that 1,000-horse power could be transmitted thirty miles on a copper conductor rod 2 inches diameter; although, to effect this, some of the electric energy would be absorbed in the heating of the conductor, occasioning, therefore, a loss in addition to that incurred in transmutation. The whole question of electric transmission is still (1880) too new to allow of any but approximate statements on this point.

Examples.

50-horse power transmuted on 2-in. rod.

Transmission on a larger scale considered feasible.

The circumstances which would favour the use of electricity as a power-transmitter appear to be :—

Favourable cases for electric transmission.

(1) Where it is desired to distribute or retail power to numerous machines far apart, where small steam-engines for each would be inconvenient or expensive.

(2) Where there are obstacles to transmission by other and more usual means.

(3) Where power from natural sources must—if it is to be of use—be transmitted.

(4) Where the two purposes of power and illumination can be combined.

In the first case—that of distribution—the loss in transmutation may, as in the case of air-compressors already described, be neutralised by the economy in fuel which a large steam-engine allows, as compared with numerous small ones; a large central engine affording at each place to which its force is retailed, after allowing for loss in transmission, as cheap a power as would a small steam-engine on the spot.

Distribution from central motor.

In the second case assumed, there are frequently occasions where local obstacles or peculiarities of site render transmission by other means difficult or impossible, but where an electric conductor cable

Electricity used where other methods impossible.

could be conveniently applied. Thus, even for small distances, a street, or river, or ravine might so interpose between a motor and a machine as to hinder the use of shafting, or even of wire rope, but which would not prevent communication by a conductor cable if the object in view were sufficiently important to justify the cost of the electric machines. There are already instances of this use of electricity.

Natural sources of power utilised.

The third case—that where there is some natural local source of power—presents entirely different conditions. A waterfall or rapid, situated within a few miles of a town might, if applied by means of a turbine or wheel to one or more dynamo-electric machines, give light to all the streets, or afford motive power to factories, without any expenditure whatever for fuel, although for cases such as these, there is not as yet much experience available.

Lighting and power alternate from same rods.

In the fourth case, there might be occasions, as in a harbour or municipal workshops, where the power transmitted by the conductor might be used in the day for working cranes or other machines, and at night time for illumination.

Fuel-force transmuted and transmitted.

If however, the utilisation by electric transmission of fuel-force derived from a colliery or petroleum oil-well situated at some difficult or inaccessible place were the object in view, the cost of conductor rods (a copper rod 2 inches diameter properly insulated costs about £2,000 per mile) would go far to pay for the construction of a road or railway for the carriage of the fuel itself; and moreover, transmission by pressure-water in pipes might in many cases be more suitable. Other electricians are quite as sanguine as Dr. Siemens in the anticipations concerning electric transmission, and foretell the time when cheap or waste fuel will be utilised at collieries for driving dynamo-electric machines, and that the power will be transmitted long distances to towns, from whence boilers and furnaces might thereafter be banished.

As from collieries to towns.

Heating of conductor rods.

As one difficulty arises from the heating of the conductor, while conveying the electric power, it has been suggested that in order to keep cool the copper conductors they be made hollow and filled with water. If copper tubes be used in this way, it might even be possible that they serve at the same time the second purpose of transmitting high-pressure water for use as power. It is (1880) too soon to speculate on the exact methods by which electric transmission is likely to be utilised, but it can hardly be doubted that it will be developed with advantage in the immediate future. If such methods prove feasible,

Hollow rods filled with water.

the utilisation of large waterfalls, even of Niagara itself, may be accomplished.

The transmission of power by *Connecting Rods* is, for general purposes, limited to very short distances; for in most kinds of machinery, a rotary motion is required; and the crank by which this is obtained from the reciprocating movement of a connecting rod, requires, for its effective working, an alternate push and pull, for which long connecting rods without intermediate supports are quite unsuited. Even in a steam-engine, the connecting rod which transmits power a few feet from the piston-rod to the crank, is made of form and strength far in excess of what the tension requires, to resist the transverse strains incurred in pushing the crank; and the rod, if its length were increased, would soon become unwieldy and impracticable. Rotary motion can, of course, by the use of a fly-wheel, be obtained by pulling only, as for instance, in a lathe where a chain connects the treadle to the crank; but in any but simple cases this is neither equable nor effective. By means of a ratchet and pawl, a slow rotary motion may be obtained from the tension of a connecting rod, but except for such purposes as a ratchet drilling-brace, or for some minor movement in a larger machine, this system of transmission is seldom suitable.

Transmission by connecting rods.

How limited.

Unsuitable for long push.

Rotary motion without pushing.

Seldom used.

Long connecting rods have found their chief application in pumping from mines, and, in recent times, for the working of railway signals and points. Pumping machinery is often erected with a view to its temporary use only; and, whether temporary or permanent, advantage is frequently taken of a steam-engine or water-wheel situated at a considerable distance from the pump-gear; and in England, connecting rods are found to transmit the necessary force without inordinate friction for distances up to 3,000 feet. Not only on the surface, but in the underground workings of a mine, power is thus transmitted, the rods working horizontally or at any inclined angle; the total distance of rod-transmission from the original motor on the surface being sometimes as much as one mile. The power is generally applied by means of a bell-crank or quadrant at the top of the mine-shaft, the crank being pulled and the vertical pump-rod lifted at each stroke of the connecting rod; the weight of the vertical rods being sufficient (they sometimes weigh more than 50 tons) to ensure the downward movement of the pump-bucket or plunger, and therefore the return stroke of the connecting rod. The distance to which it may be profitable

Long rods, how used.

For pumping.

As in mines.

By bell-cranks.

Return movement effected by weights.

See PUMPING ENGINES, *Chapter XX.*

or expedient thus to transmit power, depends on many considerations: the cost of the rods with their supports; the intervening obstacles, such as the inequality of the ground to be traversed; the loss of power by friction; the right-of-way for the rods; and the proportion which these circumstances bear to the comparative expense and the convenience of motive power placed nearer to the point where it is to operate. Such considerations have, in England, limited the transmission-distance above ground to about 3,000 feet as just stated, but under more favourable circumstances much greater distances may be traversed. Thus, in Sweden, there are instances of power derived from a waterfall or rapid being conveyed by connecting rods even as far as four miles, for use at mines; the transmission rods having often to traverse irregular and hilly country. Such a gratuitous source of power justifies a much greater loss by friction, than could be afforded if the power had to be obtained by the expenditure of fuel. The cheapness of timber for the rods, and a free right-of-way, also tend to render such long transmission feasible.

Distance, how limited.

In England 3000 feet maximum.

Power transmitted 4 miles by rods.

Loss by friction justified.

New methods of conveying power long distances by steam, water, compressed air, or wire rope, and the various modern inventions of steam-pumps, have done much to render long connecting rods unnecessary; but they are still used in the mining districts, and in the opinion of experienced engineers may very often be rightly preferred to any other system. The rods are generally of wood, strapped with iron, and are supported on rollers or rocking-posts placed at intervals of about 50 feet. Iron rods are sometimes used where the work is light; but for transmitting considerable power, stability against transverse and compressive strains is better obtained by the use of wood; and iron rods are seldom employed except for short distances.

Connecting rods still preferred in some cases.

Rods, how made and placed.

Where chain is used for pulling over a wheel, or wire rope for pulling a crank, the return-motion is obtained either by a second chain or rope, or by means of a balance-weight or spring. The two chains, which, from the steering wheel in the fore part of a ship, pull on each side of the tiller at the stern, are an example of the former method: and the wire rope and balance-weights by which railway signals are worked are examples of the latter. As chains can only act in tension, there is always a risk, where the return-motion depends on a balance-weight—that derangement in the return-motion may occur without giving any immediate indication to the operator, for the actuating lever may be duly pulled back by the local weight attached to it, even though the chain wheel at the further end may

Transmission by chains.

Examples.

Risks of derangement.

not have responded, or the chain may have buckled or kinked. The use of stiff rods instead of a flexible conductor greatly reduces these risks, because although the effective service may still be performed by tension, the resistance which a rod will — if properly guided — offer to compression, goes far to ensure the return movement. On modern ships and steamers, the steering wheels are sometimes as much as 200 feet from the rudder, and, although the force is conveyed entirely by tension, yet rods or stiff wire rope have been generally substituted for chain except at the immediate connection with the wheel and tiller. Till about 1870, railway signals within stations were almost invariably worked by wires or wire cable, and switches also, if at more than a few yards distance from the operating lever. Such a method of transmission proved quite inadequate for the safe working of a railway, under the conditions of busy traffic usual in England, and the occurrence of numerous accidents rendered improved systems necessary. Where wire or wire rope is used, and when therefore, the return of a signal to danger or the closing of rail-points at a junction depends entirely upon the action of balance-weights, there may be no immediate sign given to the signalman, if, because of dirt or snow or frost, the cranks and pulleys stick fast, for, as just explained, the actuating lever still goes back, and has apparently done its duty. But if, instead of wire rope, rods properly guided are used, they will either exert a compressive strength sufficient to overcome the obstacle, or, if insufficient, will, by preventing the return movement of the actuating lever, notify the derangement.

Chain superseded by connecting rods.

Example of tiller rods.

Railway signals formerly worked by chain or wire.

Risk of accident.

Rods now used for railway signals.

Wrought-iron tubes, which combine much strength and stiffness with moderate weight, are found most effective for transmitting the force which actuates signals and switches. The tubes employed have generally a diameter of from 1 inch to 1¼ inch, and are carried on guide-rollers placed at intervals of from 6 feet to 8 feet, and as these cause considerable friction, the force required to pull over the lever increases rapidly with the length of transmission. The stroke or travel of the rod seldom exceeds 8 inches, and where the transmission distance is great, variations in the length of the rods by expansion and contraction in a varying temperature, have an appreciable effect. The Board of Trade regulations forbid a greater distance for the working of facing-points than 450 feet, but, for trailing-points and for signals, power may be transmitted 1,000 feet. This distance may be considered the limit of transmission by connecting rods for these purposes, and for longer transmissions — such as for distant signals

Railway rods, how made and placed.

See TUBES, *Chapter XX.*

Affected by varying temperature.

Board of Trade regulations.

Limits of distance.

which are sometimes placed as far as 4,500 feet from the operator—wire rope is used.

See RAILWAY SIGNALS, *Chapter XXI.*

Growth of English system.

The constantly increasing traffic, the high speeds, and the general adoption of the block and interlocking systems on English railways, have greatly enhanced the importance of adopting the best transmission methods; and the constant attention of railway engineers has brought the various kinds of apparatus to a high degree of perfection. With regard to the connecting rods or tubes, further improvement is still sought in the methods adopted for meeting alterations in temperature; the various systems now in use not always proving effective. It is generally sought, by dividing the total length into sections, to make an expansion in one section compensate exactly for an opposite expansion in another; but even this precaution sometimes proves insufficient where the variations in temperature are irregular—as for instance, where part of the rods are situated in a tunnel or deep cutting, and the remainder on an exposed embankment.

Improvements still sought in compensators.

Transmission by shafting.

Short distance for gross power.

For distributing power to numerous machines, *Shafting* is almost invariably employed; but for conveying gross power, it is only expedient to use shafting for short distances, an engineer's factory or a cotton mill being an example of the former, and the fly-wheel shaft of a land engine, or the screw-shaft of a marine engine, examples of the latter. The engine or other motor is placed as near the point of distribution as possible, as the cost of the machinery and the friction in working, increase rapidly with the distance of transmission. In England, it is the general practice to take the power from the main shafts of large fixed engines by toothed wheels to one or more secondary shafts, from which the power is distributed by pulleys and belts to the various machines. Where the power has to be conveyed in numerous directions or to many different workshops, the principal transmissions are either effected by toothed wheels or by belting, the former plan being the most frequent in England. But the use of toothed wheels greatly limits the speed of the shafts, and it is on the principle that quickly-running shafts are the most economical for transmitting a given power, that belting is preferred more often than formerly.

See page 105.

Toothed wheels and belting.

Toothed wheels limit speed.

See BELTING, *page 105.*

The laying out of shafting.

The primary consideration in laying out shafting, is to have the supports at proper distances apart, so that while, on the one hand, there may be no unnecessary bearings (as each adds to first cost and

to the friction of working, as well as being an obstruction) there may, on the other hand, be no risk of flexure with shafts of moderate diameter. Some distance between 8 and 12 feet is generally adopted where there is free scope for choice; the lighter the shafting the nearer the bearing required. In cases where it is impossible or inconvenient to have bearings so near—as for instance where a shaft spans an open yard or public street—it may become necessary to truss the shaft to enable it to resist flexure. Another important consideration is the arrangement of bearings, couplings, and power-transmitting pulleys in relation to each other, for it is expedient to have couplings as near the bearings as possible, and it is even more important that the power-transmitting pulleys should also be arranged near bearings, for they impose great strains upon the shaft. Shafting which conveys power in the gross, that is to say, which transmits to one end the entire power it receives at the other, must be of uniform diameter; but the general use of shafting is to distribute power, and in such cases it is made to diminish in diameter with the distance from the motor, as the power becomes less by that abstracted. For any but moderate distances, it is expedient to place the steam-engine or other motor in the middle of the line, and to take the shafts right and left from it, so as to diminish the length of each. In this way, shafting is taken as far as 1,000 feet in either direction from an engine, but although, by careful arrangement and workmanship, the friction can be minimised, the loss is considerable, and such long lines of shafting are only expedient when the necessities of distribution along the line are such as to justify a considerable expenditure of power in conveying it. Where there is but one or few machines, a separate motor close to the machine, or transmission by wire rope or water would generally be preferable.

Distance apart of bearings.

Couplings and pulleys.

Should be near to bearings.

Motor placed midway in line of shafting.

Long line shafting causes loss of power.

The details of shafting, and its various accessories, have been brought to great perfection. The shafts themselves, for diameters not exceeding 4 or 5 inches, are turned from solid rolled bars of wrought-iron, but it is sought in some cases to avoid the expense of turning, by using bars so planished by cold-rolling as to have a bright smooth surface. Large-diameter shafts are forged under the steam-hammer and then turned in the lathe, though sometimes only the journals or bearings are turned. The exact form which turning alone gives, is, however, very useful in allowing free scope for bearings or pulleys at any point, and every wheel, pulley, or coupling should be balanced. The importance of these precautions increases with the

Shafting, how made.

Large shafts.

All revolving parts should be turned and balanced.

velocity, for as any irregularity in form, or want of balance in the shafts or pulleys, gives, at each revolution, a blow to the fixed parts, the vibration from these causes will, at high speed, shake loose or destroy the entire apparatus; while rough or seamed journals cut or wear away the bearings. For high-velocity shafts conveying considerable power, or where the distance between the bearings is necessarily great, hollow tubes have in some cases been used, so that while retaining a diameter sufficiently large for the bearings and to resist torsion or flexure, the weight may be as little as possible. There are great differences of opinion as to the methods of coupling shafts —flanges, sockets, bolts, and keys being applied in various ways. The coupling should be so designed that the shaft is at least as strong at the coupling as anywhere else, and it may be said generally that standard sizes should be adopted, so that couplings of the same nominal size may be interchangeable and fit accurately on shafts of given diameter: and the shafts should be so regulated in size as to allow the free passage over them of any wheel or pulley which it may be desired to attach.

Especially for high speeds.

Hollow shafting.

Couplings.

Standard sizes.

Bearings or supports for shafting are needed in a very great variety of form and size; wall-brackets, column-brackets, hangers, and pillow-blocks of varying dimensions being necessary for the different situations that present themselves. And when belts are substituted for geared wheels, the exigencies of position or angle frequently require swivelled or adjustable bearings of various kinds. The frequent bearings for shafting of course require beams, columns, or walls for support, and it is best to have all these under cover. Sometimes, these necessities may be modified by laying the shafting in a trench in the ground, a plan frequently adopted, for instance, in a saw-mill, where overhead belts would hinder the free moving of timber, and where, because of the high speed of the shafting, the solid support of the ground is advantageous, as affording a steadier bearing than the elevated or side supports of columns or brackets. Where the machines are so placed that the belts from below form no obstruction, the plan may be best, but it has certain inconveniences.

Various kinds of supports for shafts.

See FACTORIES, *page 68.*

Bearings should be under cover.

Shafting laid below ground.

Reasons for and against.

The shafting of a factory with its numerous bearings, couplings, wheels and pulleys should be considered, not only in relation to its ultimate purpose of transmitting power, but as itself a machine. On the proper proportioning of the various parts, on the balancing of quickly-revolving wheels and pulleys, on the accuracy of the bearings, and on the methods of lubrication, depend not only the cost of

Shafting considered as a machine.

Cost of working, how determined.

repairs; but the daily cost of keeping the whole in motion. Many factory-owners are quite ignorant of the power absorbed in doing this, and the measurement of the force expended in turning the whole while all the machines are idle, would often be very useful. The power thus absorbed frequently exceeds 25 per cent., and in some cases amounts to 50 per cent., of the gross force of the motor; and where the work of the machines is intermittent and much shafting is kept running without doing useful work, the proportion of unremunerative expenditure will be greatly increased. In large factories, where the work to be done is constant and uniform, one central engine of considerable power generally proves cheapest, as space, fuel, and attendance are economised; but where, as in an engineering factory, one or few machines may, at times, alone be wanted, it is becoming usual to have numerous small engines and less transmission shafting. For, in regard to the first cost of the apparatus itself, of the preparations for supporting it, and the force expended in moving it, shafting is an expensive mode of transmitting power long distances or to isolated machines; and in such cases the question arises whether a separate motor would not be better, and, if a local boiler for a steam-engine be inconvenient, the transmission of the necessary power by steam, water, wire-rope, or electricity from a distance. The choice among these methods depends not only on the local circumstances which make the course to be traversed convenient to one more than to the other, but on the nature of the operation to be effected—revolving or only reciprocating, constant or intermittent, slow or quick in its movement, whether requiring much or little force.

Great loss of power in transmission.

One central engine and much shafting.

Numerous small engines and less shafting.

See SMALL ENGINES, *Chapter XIX.*

Choice of method, how determined.

See also page 71.

Power is in some cases distributed by shafting to different users, who pay rent for it, this custom prevailing in many manufacturing towns where craftsmen of various kinds require from ¼ to 10 horse-power for driving their machines. Sometimes, the power alone is hired, but generally it is provided by the landlord of the tenements—often a factory-owner, who has spare rooms to let—the tenants who thus hire power as well as room, having, of course, to conform to the prescribed hours of working, or to pay at a higher rate for extra hours if the steam-engine be kept running for them alone.

Power by shafting sold to users.

Power leased and included in rent.

Belting may be said to find its principal use in the distribution rather than in the transmission of power, and even those engineers who prefer geared wheels to belting for conveying gross power from a steam-engine or other motor, generally agree that belts are best

Transmission by belting.

Belts preferred for distribution. suited for distributing or retailing power to numerous machines. There are, however, great differences of opinion as to the comparative advantages of belting and geared wheels, and lengthy treatises have been written on both sides without settling the question. But although there are some occasions in which the choice between the two methods may be difficult, the circumstances which favour one to the exclusion of the other are in the majority of cases easily distinguishable.

Belts not preferred for slow speeds. Belt-transmission does not compare favourably with gearing for slow speeds, and when it is so used it is because of the supposed cheapness or simplicity allowed in the construction of the apparatus, or because of special difficulties in the way of gearing. **Nor for exact speeds.** Belting is not suited for transmitting exact speeds, for there is a liability to slip, which varies according to tension, temperature, tightness of the belt, smoothness of the pulleys, and other circumstances. Thus, it is unfitted for a clock or indicator, for the screw-cutting apparatus of a lathe, or for giving motion to the governor of a steam-engine; although it is frequently used for the latter purpose where great exactitude is not required. **Pitch-chains.** *See page 111.* Pitch-chains used as belts meet, to some extent, this difficulty. **Slipping of belts.** The slip, or "creeping," of a belt varies according to its grip, and to the strains put upon it, and it is evident that where there are several successive transmissions, the aggregate slip may alter greatly the proportionate revolutions of the power-receiving machine and the motor. **Grip, how increased.** The grip of a belt can be increased by covering the pulley with buff-leather, paper, or other material which increases the friction; but such methods are seldom adopted except for special purposes and small machines. For wire-rope transmission the pulley grooves are always covered, but as much to prevent damage from the rubbing of two metallic substances as for giving grip to the rope. Chalk or resin is often applied to belting to increase the grip on the pulleys. **Slipping sometimes an advantage.** The liability of a belt to slip, while incompatible with exactitude of speed, is, however, the very circumstance which renders this kind of transmission preferable to gearing for certain operations. Thus, for instance, in driving a circular-saw, if the timber be pushed forward too rapidly, or a hard knot be encountered by the saw, some part of the apparatus must yield or break; and the belt, slipping on the pulley, **Instances.** affords the necessary relief. So, also, in starting machinery—if toothed wheels, running at a considerable speed, be thrown into gear with a heavy machine, the inertia of the latter cannot immediately be overcome, and there is a liability to fracture. A belt transferred in the usual

way from a loose to a fast pulley acts in such a case the part of a friction clutch, and slips sufficiently, during the first few revolutions, to give time to the power-receiving machine to attain its proper speed. **Fast and loose pulleys.**

Belting is obviously more convenient than gearing for temporary transmission, or where the distance from the motor to the machine or the relative level of their positions is liable to variation, as a belt can be readily applied and adjusted without the preparation and exactitude which geared wheels and their supports involve. Thus, from a portable engine to a thrashing-machine, stone-crusher or mortar-mill, the gross power of a steam-engine is always taken by belting. **Belting convenient for temporary use.** **Instances.**

Belting has generally been considered by English engineers as unsuitable for transmitting the gross power of large engines, but the example set in the United States, of using belts instead of toothed wheels for such purposes, has been followed by many engineers in England. And though in confined spaces, or where it is necessary from the nature of the apparatus that the transmitting parts shall be compact and unobtrusive, gearing would appear to be more convenient than belting, in America the custom is extending of designing machinery with a special view to the use of belts. Even for purposes so far beyond its hitherto-considered-legitimate function as the giving motion to bar-iron rolling-mills, belting has been applied with success. **Transmission of gross power by belts.** **As in America.** *See also page 108.* **Extreme case.**

The whole subject of belt-transmission has been thoroughly investigated, and elaborate tables, based on numerous experiments, are available for reference. Opinions differ not so much in regard to the theory of calculation—for there is a general concurrence as to the principles involved—as in regard to the deductions drawn and in the working rules recommended. The power which a belt can transmit is measured by the strain or tension imposed on it (depending on its sectional area and the quality of the leather) multiplied by the velocity, the foot-pounds of energy per minute thus transmitted being equal to a certain horse-power. The ultimate breaking strain of leather belts varies, according to their kind, from 3,000 lbs. to 5,000 lbs. per square inch of sectional area, but there are wide differences of quality. The effective strength is limited by that of the lacing or riveting by which it is joined, and the leather becomes worn and weakened by use. It is considered expedient, therefore, to have a considerable margin of strength, and a working strain of from 300 lbs. to 350 lbs. per **Theory of belt transmission.** **Power depends on tension.** *See* HORSE-POWER, *Chapter XIX.* **Strength of belts.**

Working strain on leather belts. square inch of sectional area is usually adopted; from 55 lbs. to 60 lbs. tension on a belt 1 inch wide $\frac{3}{16}$ thick being an example. From the gross tension given to the belt, has to be deducted, to obtain the net result, a certain proportion which serves only to overcome friction on the pulleys, and though there are variations in friction arising from **Allowance for friction.** different causes, one-fourth is generally considered a fair allowance. As an approximate rule, a belt-surface velocity of 55 feet square per minute may be taken as required for each horse-power transmitted, but as belts vary in thickness, such a rule may need qualification, belts of double or treble thickness affording increased strength in pro- **Large driving-belts in America.** portion to their greater sectional area. In the United States, where—as has been said—belting is used for transmitting much greater power than is usual in England, main driving-belts are made of all widths up to 36 inches, and 4,000 to 5,000 lineal feet per minute is considered **High velocity.** a proper speed, this speed being obtained more by the use of large diameter pulleys than of high-speed shafting.

Distance apart of pulleys. Belting works most effectually when the pulleys are at such a distance apart, that the weight of the upper belt affords considerable adhesion on the pulley, and the belts should be of such width and have such a contact with the metal as to transmit the desired power when **Extreme tightness to be avoided.** thus running slack; for if the adhesion has to be obtained by extreme tightness of the belt, the shafting is too much strained. Belts always incline to the greatest diameter of a pulley: hence the rounding of the rim prevents the belts slipping off. If however, the distance between the pulleys is too great, the belts—slacker as their length increases—work unsteadily, especially at high speeds, and become cumbersome and dangerous. Between main-driving pulleys, the dis- *See* WIRE ROPE, *page 111.* tance seldom exceeds 40 feet, and between minor distributing pulleys 25 feet, while in the majority of cases, shorter distances are usual. For longer spans, in exceptional cases, intermediate pulleys or rollers both for guiding and tightening the belts, become necessary. Moreover the belting can then be enclosed in wood casing.

Twisted belts. Power can be transmitted by belting from one shaft to another not parallel to it by twisting the belt, and the belt has then a greater grip-surface on the pulley; but unless carefully effected, excessive side strains may be imposed on the shafting or machines. Difficulties of **Intermediate pulleys.** this sort are overcome by having intermediate pulleys for altering the direction of the belting; and where so guided, power can be transmitted round corners, although the loss by friction is by such a method much increased. Where the direction or line of transmission is sub-

ject to variation, swivelled pulleys allow the necessary latitude to the belting. **Swivelled pulleys.**

Although leather is the most usual material for flat belting, other materials are also employed; canvas, vulcanised indiarubber, or both combined, and gutta-percha, being the most common substitutes. These materials are considered preferable sometimes when the belting is to be exposed to damp or steam, but they are also used where no such conditions prevail, because they may be at a particular time and place cheaper than leather. The quality of leather differs very much in different countries, and the superiority generally conceded to English leather lies rather in the mode of manufacture than in the original quality of the hides. Bark-tanning produces the best leather for general purposes, and the English climate favours the growth of the best oak bark. A variety of other materials—hemlock bark, gambia, valonea (oak-apples), myrabolams—are employed for tanning where oak bark is scarce, but the average quality of leather so produced is less. In England, moreover, more discrimination is exercised in dividing the hides into various parts for different treatment; so that even though the same average of quality may be produced by foreign tanning, the better parts of the hide receive in England more attention, and afford for those who are willing to pay, the best leather.

Materials for belts other than leather.

Quality of leather.

Bark tanning.

Substitute for bark.

High-quality leather.

But although leather of the best quality for general purposes may be produced by oak-bark tanning according to the English system, it is a much-disputed point whether leather so manufactured is the best for all purposes. For instance, hemlock-tanned leather, though not of such good appearance, is extremely hard and durable for boot soles; and similarly, in the opinion of some engineers, the oak-tanning process, carried out in the manner usual in England for high-priced leather, is not the best suited for belting, in that it reduces the original tenacity of the hide. A lasso rope of dried hide is, for instance, stronger than a similar rope of leather, and the tedious manipulating process by which, in the preparation of such lasso ropes, the flexibility of the hide is retained, has been imitated by a machine process for making what is called "fulled raw-hide leather" for belting. The qualities of leather so made have not, however, been sufficiently tested to justify its general adoption in preference to bark-tanned leather, and except where it is important to obtain a maximum tensible strength, the latter would probably be preferable.

Hemlock-tanned leather.

Dried hide lasso rope stronger than leather.

Round ropes are frequently used instead of belts, partly because of **Round ropes as belts.**

the direct advantages they are supposed to afford, and partly because where good leather is scarce, they facilitate the substitution of other materials. Belting ropes are made of leather, raw or half-tanned hide, hemp, manilla, or cotton. Leather of inferior quality, which would fray or break if used in the form of a flat belt, may be twisted into a very strong rope. One effective method of doing this is to lay a flat belt upon another of double the width, unite them by one row of stitches down the centre, and then to twist the belt, thus doubled, into a rope. Raw or half-tanned hide has, when twisted into a rope, a tenacity 1½ times that of flat leather belts of the same sectional area. Ropes are often more convenient than flat belts, and in some factories—mostly in the United States—have entirely superseded them. A flat belt is often inconvenient, its edges are obtrusive, it requires wide pulleys, and, if the transmission be not in a direct line, elaborate arrangements for directing it. But even where there are no such special circumstances, ropes are preferred by some engineers. Single ropes are used for distributing power to small machines, but the system is characterised by the use of numerous ropes running on the same pulley in a series of grooves side by side. Thus—to take one instance—in a jute factory at Calcutta the entire force of an engine of 1,000-horse power is taken by 18 cotton ropes from the fly-wheel, which is made of a drum form, 6 feet 7 inches wide, to receive the necessary grooves. The fly-wheel is 28 feet in diameter, making 43 revolutions per minute, the ropes being each 2 inches diameter, 11 of the ropes taking the power in one direction and 7 ropes in the other. The subsequent transmissions for distributing the power are made also in a similar way, smaller and fewer ropes being used as the power becomes less. But to work this system effectively the pulleys and grooves should be acurately turned, so as to ensure that the working diameter at each groove is exactly similar. And as, to carry out this, the ropes should be of the same diameter, no new rope should be inserted till by stretching, or otherwise, it is the same as the ropes that have been strained in working.

Materials for round ropes. **Leather rope.** **Hide rope.** **Advantages and drawbacks.** **Numerous ropes in grooved pulleys.** **Example.** **Precautions necessary.**

Cotton and hempen ropes. There is said to be less risk of stoppage with cotton or hempen ropes than with the usual flat-leather belting, as the ropes, which are worked at strains very much below their ultimate strength, give early warning of deterioration or coming fracture; and even the breaking of one out of numerous ropes does not involve the stoppage of the machinery, a new rope being substituted after working hours.

There is the disadvantage in rope-transmission of this kind that the

arrangement usual with belting, of fast-and-loose pulleys for starting and stopping the machinery cannot be adopted, and other means have to be used instead. **Starting and stopping.**

Another method of power-transmission which may be included in this category is that by pitch-chains, which, though not suitable for the usual purposes to which belts are applied, can, under certain circumstances, work effectively at low speeds. Such chains have no slip, for each link of the chain fits upon a tooth of the pulley-wheel, and the driving and receiving wheels maintain a similar or exactly proportionate speed according to the number of teeth on each. Indeed, transmission by pitch-chains may be considered as an elongated or extended system of spur-wheels. Pitch-chains are sometimes used, not because they are without slip, but because in the open air they are more durable than leather or rope belts, or because they can be used for longer distances; in this latter respect performing somewhat the same function as a wire-rope transmitter, presently to be described. Pitch-chains are often used in England in brick-fields or other situations where the work is rough. **Transmission by pitch-chains.** **Have no slip.** **Occasions for using pitch-chains**

Transmission of power by belting, including in this term the rope substitutes above described, is, as has been already stated, limited to very short spaces; and for longer distances rope-transmission of a different kind becomes necessary. **Belting limited to short spaces.**

The opportunities for the transmission of power by *Wire Rope* may be said to begin where those for belting end; but for distances up to 100 feet, or even 150 feet, shafting is generally to be preferred. The teledynamic cables—as the endless, transmitting ropes are called—are of comparatively recent introduction (few were in operation before 1860) and have been only rendered possible by the modern invention of wire ropes; but on a much smaller scale, and with hemp or cotton ropes, somewhat the same system was at an earlier date employed for short distances. Transmission by hemp or cotton ropes is in this way found convenient where the power-receiving machine is at a varying distance from the motor. Thus, in a travelling-crane, a rope running from end to end of the staging or gantry may be passed round a wheel on the travelling-bridge, and without any alteration in length may draw the bridge backwards and forwards at will. In cranes of this sort, it is sometimes undesirable or inconvenient to have workmen on the crane itself; and the entire working of the winch, and the various travelling motions, may be **Transmission by wire rope.** **Teledynamic cables.** **Hemp or cotton ropes.** **As used in travelling-cranes.**

See CRANES.

performed from below by the rope, more conveniently than by shafting. Where the travelling-crane is protected from the weather, cotton or hempen ropes will suffice, and a rope $\frac{5}{8}$ in. diameter will propel the travelling-bridge, the traversing winch upon it, and lift weights up to 10 tons easily and quickly.

Used on traversers.

See RAILWAY TRAVERSERS, *Chapter XXI.*

Another example is that of a railway traverser for conveying locomotives or carriages across a railway station, or a still longer distance across many lines of rails in a station-yard. A hempen rope $\frac{1}{2}$ inch diameter, laid in an open trough a few inches below the ground and passing at one end round a drum on a motor shaft, and, in its course, round a wheel on the traverser, will draw or propel heavy loads smoothly and quickly. On a still larger scale, and with wire rope, the same principle has been carried out for propelling tramcars; the system being particularly useful where the gradients are too steep for horse traction, and steam-power is forbidden. In San Francisco, a tramway having some steep inclines is successfully worked by wire rope laid in a covered trough below the track. By running at a high speed, considerable power can in this way be transmitted by small ropes, but the power is of course much less with hempen rope than that which wire rope will transmit, and any other than wire ropes would, if made strong enough to resist as great a tension, be large and cumbrous. Moreover, hemp and cotton deteriorate rapidly if exposed to grit, damp, or steam; and, unless protected from these contingencies, frequent repairs and renewals become necessary. Wire ropes, because of their superiority in these respects, are generally preferred, and are rapidly superseding hemp and cotton ropes. On the other hand, unless the wire rope be of good quality, twisted in the manner suited to the purpose in view, and the pulleys properly constructed, the ropes will fray or kink.

Tramcars propelled by endless rope.

Small ropes at high speed, transmit great power.

Hemp and cotton decay.

Wire rope preferred.

Wire rope proved by experience.

The introduction of wire rope and its adoption for the standing rigging of ships, for hauling wagons up inclines, and for drawing from mines, sufficiently proved its strength and endurance; and the application of it for power-transmission is the logical outcome of this experience. Iron and steel are at their strongest in the form of wire, which in proportion to its diameter or sectional area, has a tensile strength twice as great as the bar from which it has been drawn. The breaking strain of iron wire is at the rate of from 80,000 lbs. to 110,000 lbs. per square inch of section. Several wires being twisted into a strand, the rope is generally formed by twisting several strands round a hemp core; ropes or cables so made, having the aggregate

Iron and steel strongest in form of wire.

Wire rope, how made.

strength of all the wires, less a diminution calculated at from 5 to 10 per cent., for loss by twisting. The exact strength and flexibility of a wire rope depend upon the quality and temper of the wire, and the manner in which it is twisted; and as several varieties of wire rope are made, the manufacturer should be informed of the purpose for which the rope is required, the diameter and kind of pulleys, and the tension at which it is to be worked. An iron rope ½ inch diameter will bear from 3 to 4 tons tension, and an iron rope 1 inch diameter 10 to 15 tons before breaking; a 1-inch steel rope, if hard, as for ships' rigging, will bear 28 tons, and if flexible, for moving round pulleys, about 20 tons; one-sixth being considered a fair working strain.

Strength and flexibility vary.

Strength of iron and steel rope.

Working strain.

The amount of force or energy which a rope will transmit in a given time, depends upon its tension multiplied by its velocity, the foot-pound units so ascertained corresponding to a certain horse-power. It is the application of this principle which forms the basis of the teledynamic cable system. Ropes of small diameter are utilised by running them quickly, the desired speed being obtained by making the transmitting pulleys on the motor shafts of large diameter. In practice, the pulleys are of all sizes to 15 feet, and cables of from ½ inch to ¾ inch diameter, with speeds of from 3,000 to 5,000 feet per minute (about 30 to 50 miles per hour) transmit any required force up to 400-horse power. As the rope is subjected to a strain from flexure as it passes round pulleys, and as it has, moreover, to sustain the weight of its own catenary when suspended, the tension from these causes must be deducted before the effective strains can be arrived at. The amount of non-effective tension depends on the diameter of the rope and that of the pulley, and on the length of the spans. The power is taken by the rope passing round a grooved pulley of large diameter on the motor shaft, and, like a belt, transmitting the force to another pulley at a distance. The pulley to which the force is thus transmitted has a second groove upon it from which another rope conveys the power onwards to a third shaft, and so on by a succession of stages for a mile or more. In the most notable examples of this system, the total distance varies from a quarter-mile to one mile; but it has been calculated on the basis of experience already acquired, that 120-horse power could be transmitted twelve miles with a loss only of one-fourth in the process. Difficulties connected with right-of-way, and the protecting and keeping in repair so many moving parts extended so far, render the opportunities for such long transmission rare, and two miles would be generally the practicable limit.

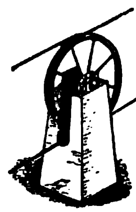
Force transmitted depends on tension and velocity.

See HORSE-POWER, *Chap. XIX.*

Usual speeds.

Non-effective tension.

Mode of working.



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Usual distances.

Difficulties.

Length of spans. The separate spans vary from 300 to 500 feet, and though it is not easy to determine the maximum space which would be practicable, it would certainly not be less than 600 feet. But, while long spans like these are feasible, there is necessarily a considerable deflection or sag, and if the rope be not high enough to clear the ground, idle pulleys or rollers must be placed as intermediate supports. Power is thus conveyed long distances, not only horizontally, but up and down hill (though the weight of the cable limits the ascent), across rivers and ravines, and even through water. Cases arise where the power of a steam-engine may with advantage be thus transmitted to a distance, but the system finds its chief application in utilising the natural force of water, by transmitting it to a convenient place. Power from a water-fall or rapid is sometimes conducted down stream by conduits or pipes laid parallel to the river; but by wire ropes the power can if necessary be taken up stream or across it.

Deflection of ropes.

Power taken up-hill and across rivers.

Water-power transmitted by wire rope.

Choice of methods depends on purpose. Wheels or turbines having been first employed to develope the power, wire rope, compressed air, and high-pressure water are all utilised for transmission, according to the purpose for which the power is to be applied and other local circumstances. Thus, for saw-mills or factories needing rotary motion, it is wire-rope which will generally best convey the power; for mining operations below ground or subaqueous work, compressed air; for cranes and very small motors, water or gas-fuel; while, if the distance be great, or if there be serious difficulties in the way of pipes or ropes, the power may be transmuted into electric force and transmitted by conductor-cables or rods of copper.

Examples.

Power-transmission in Switzerland. The whole question of power-transmission has attracted most attention in Switzerland, where waterfalls and rapid rivers abound; but where, in most cases, the site and immediate vicinity of the fall are not suitable for factories. At Oberusel near Frankfort, the motive power of a waterfall 263 feet high is utilised; and about 100-horse power is transmitted by wire ropes more than 3,000 feet horizontally and 145 feet downwards, in spans of about 400 feet. At Schaffhausen, the current of the river Rhine is utilised by turbines of more than 700-horse power, and the power is transmitted by wire ropes to numerous factories. At Fribourg, situated on the Saone (a branch ot the Air); at Bellegarde, where the *Perte du Rhône* represents probably a force of 2,000-horse power; and at Zurich, where the lake discharges by the river Limath, the natural forces of the water-flow are utilised and transmitted by wire ropes; the system having

Water-power transmitted by wire rope.

See VIGNETTE, *page 70.*

in these cases a particular value owing to the dearness of fuel for steam-engines.

Distribution of power by wire ropes.

Example at Zurich.

Power is also distributed from one part of a factory to another by wire rope. Thus, in Zurich, a large ironworks on the river front has its two principal departments separated by a large block of municipal buildings; and as all the power is obtained from water-wheels at the one department which was first established, a portion of the power is transmitted by wire ropes along the river front, past the municipal building to the second department. So again, at a factory situated some distance below Schaffhausen, part of the power, collected and chiefly utilised on the left shore, is transmitted across the river Rhine to premises which have been built on the right shore. Wire-rope transmission is useful also for collecting power from different sources to one common centre, an inversion of the distributing principle described above. Thus at Kehlhof in the Toess Valley, a cotton-spinning factory derives power from an adjoining waterfall; but this being insufficient, the force developed by a turbine from another fall nearly a mile lower down on the same river, is brought back to the factory by wire rope to supplement the local power.

Rope across the Rhine.

Collection of power.

Instance.

Commercial conditions of power-transmission.

As in Switzerland.

As various plans for the transmission, distribution, and sale of power are receiving a wider attention than formerly, some reference to the commercial conditions of any such undertakings may not be out of place. In Switzerland, power-transmission by the wire-rope system is undertaken by private persons—or, if it be the purpose to distribute power to numerous users, by a joint-stock company; and sometimes—especially when allied with a water-supply scheme—by the municipal authorities. The power is leased or sold to factory owners and craftsmen of various sorts; and, as the force transmitted by the various ropes depends on the tension and speed, the proprietors of the transmitters can control the distribution and measure the power they supply. The various Swiss associations which have been established for the transmission of power by wire rope, have not, hitherto (1880) reaped the anticipated profit; but the reasons for this, though they may for a time postpone, are not such as to hinder, the further development of the system. At Fribourg and Bellegarde, the wire-rope undertakings have been financially unsuccessful, not on account of engineering errors either in the water-motors or rope-transmissions, but from economical mistakes in the extent of the works, the capital outlay, and the expected earnings.

Sale of power.

Wire-rope companies.

Fribourg and Bellegarde.

Want of success. The mere creation of powerful motors and the distribution of power at low prices will not at once transform an isolated locality into an industrial centre; and it has been found, in the two instances named, that there are not at once forthcoming enough enterprising manufacturers and suitable workmen, to utilise and pay for the power so **How explained.** cheaply and conveniently provided. The depressed condition of business all over Europe in the years following the starting of the apparatus, checked the improvement in these respects which was hoped for. The commercial arrangements of the transmitting associations at Schaffhausen and Zurich may, however, be examined with more advantage.

Rope transmission at Schaff hausen. At Schaffhausen, where the Rhine separates the Canton of that name from the Canton Zurich, three large turbines, of 200, 250, and 250 horse-power respectively, are fixed on the left or Zurich shore. Of the total 700-horse power thus produced, 200-horse power is taken immediately by shafting to a large thread and canvas-hose factory **Across the Rhine.** close by, and the remainder is transmitted by wire ropes, across the river, to pulleys on a strong pillar or framing erected on the Schaffhausen side. Here, by gearing, the transmission is diverted at a right-angle to a line of wire ropes, conducting the power along the **And along the shore.** bank of the river, in spans varying from 380 to 440 feet; the transmission extending (in 1878) for four spans, thus involving five relay stations or pillars. At each of these stations, power is taken away **Distributed to users.** and distributed over a considerable tract—nearly half of the town—and is utilised for various manufacturing purposes. Thus, from station No. 1, whither the power is first brought across the river, three factories derive 11, 2, and 4 horse-power respectively. From **Small power taken.** station No. 2, three small factories take 1, 2, and 2 horse-power; from station No. 3, a line of shafting running underground for 406 feet up one of the streets at right angles to the river, takes power to eight factories, using from 2 to 6 horse-power each. The aggregate power abstracted up to this point is comparatively small, and it is at Station No. 4 that the most important distribution commences. **Large power taken.** One large worsted-spinning factory takes 265-horse power; an industrial dwellings association 80-horse power; and three other factories take 14, 6, and 2 horse-power; the last of these obtaining the power direct from No. 4 station by a light wire-rope transmission. **Power sold to workmen and included in rent.** The industrial dwellings association has been formed especially for giving workmen and others manufacturing on a small scale, power as well as room at one inclusive rent. The wire-rope transmission

up to No. 4 station has been working since 1866, and it was only in 1875 that it was continued to its next terminus at No. 5, from whence three factories take 3, 3, and 38 horse-power respectively. At the commencement of the year 1879, a total of 664-horse power had been contracted for, it having grown to this amount from a total of 121-horse power taken in the year 1866. It is interesting to note how a small community (the population of the town has fluctuated since 1857 between 10,000 and 13,000) has utilised so largely, and in such a variety of undertakings, the water-power within its reach. In addition to the distributing system above described, there are numerous water-wheels and steam-engines belonging to independent proprietors.

Total power sold

The price paid for power from the wire-rope stations ranges from 120 fr. to 150 fr. per horse-power per annum; and, in some cases where local transmission-shafting for bringing the power to the outside of the factory of the hirer is supplied, an additional charge of about 30 fr. per horse-power per annum is made. The turbines and wire rope run twelve working hours per day, and are stopped during the night, on Sundays, and on four holidays in the year, to afford opportunities for repair. If necessary, for important alterations or repairs, stoppage to the extent of twenty working days per annum, may be made without compensation to the hirers; but beyond this, a rebate in the rent may be claimed by them.

Price paid for power.

Conditions of sale.

The company which owns the transmission system at Schaffhausen was formed with a capital of 800,000 fr., of which the town contributed 300,000 fr.; but a much larger sum has been expended on the works by the principal promoter of the enterprise. The dividends have, in some years, been *nil*; in 1877 they had reached 3 per cent; but the low profits were mainly owing to the very low tariff; the whole undertaking having been carried on rather as a work of public utility than for gain. It can, however, hardly be doubted that on the expiration of the original leases with the factory owners, if the system has then become thoroughly established, the tariffs may be considerably raised while still affording cheap power to the users. In estimating the value of power provided in the manner here described, and in comparing it with that afforded by a steam-engine, it must be noted, on the one hand, that the capital necessary for independent motors is saved to the hirers, as well as the fuel which a steam-engine would consume; while, on the other hand, the terms of the contract do not allow any diminution in rent, if, for any reason, the power is not made use of.

Capital invested in undertaking.

Profits from low tariffs.

Value of rope-power compared with steam-engine power.

Rope transmission at Zurich.

At Zurich, the utilisation of the river current has been undertaken by the municipality, who had already, for some years, carried on for the advantage of the town the transmission of power by water as already described; but new works on an extended scale have since been constructed which embrace a considerable system of wire-rope transmission. Dikes and dams have been built to regulate the flow of water to ten turbines, of force together equal to 900-horse power.

Power obtained from turbines.

Of this, the principal part is applied directly to the pumping of water to elevated reservoirs for an extension of the high-pressure water-transmission system just mentioned, which has been very successful, and which required considerable additions to meet the demands upon it. The power from two turbines is taken across the river by wire ropes and transmitted to three already existing factories, which were disturbed by the new works and had a first claim for power. The same pillar or station which receives this power from the turbines receives from 200 to 300 horse-power for transmission along the river-bank to industrial dwellings: the ground for these fronting the river having been secured by the municipality, who let out to tenants workshops and power at an inclusive rent, somewhat in the manner adopted at Schaffhausen, but at a higher tariff. The tariff is, however, much less than that for pressure-water power for the hydraulic engines.

See page 78.

Power taken across the river.

To industrial dwellings.

See page 117.

See page 78.

Wire-rope and water systems compared.

As the wire-rope and water systems work together in the same town, the different conditions must be taken into account if a comparison be made between them. Where the force is derived from the weight or gravity of stored-up water, the expenditure of energy in producing it, is regulated exactly by the water consumed by the users; and as the water unconsumed on one day is left available for use on a future occasion, payment need only be made for the precise quantity used; while in the wire-rope transmission, the power of the motor and the expenses of managing it cannot be exactly regulated to meet a fluctuating demand; and users must pay a rent, measured, not by what they actually use, but by what they have the option of using if they please, and which in any case is provided.

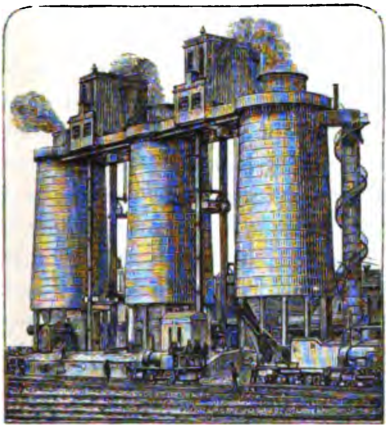
Conditions of price differ.

Choice of method, how determined.

The various means of transmitting power which were summarised on pages 71–2 having now been described, it may again be said in conclusion, that a choice between them in any particular case can only be made after consideration of all the circumstances enumerated on page 71, full information about which should be furnished to those concerned.

CHAPTER XVIII.

THE COMMERCE IN COAL, IRON, AND STEEL.



ENGINEERS are concerned in the uses of *Coal* in various ways, but mainly for the evaporation of water in steam-boilers; the smelting of ores; the melting, puddling, and other processes of iron-making; the making of steel; and the production of illuminating gas. For these very different purposes, each kind of coal has its particular value. The comparative powers of the different kinds consumed in generating steam are generally expressed by the number of pounds of water which are evaporated by the combustion of one pound of coal, and the power and value of coal in this respect mainly depend upon the amount of carbon and hydrogen it possesses. One pound of English coal will evaporate from 6 lbs. to 11 lbs. of water, and with limits so wide, the proper choice of coal is evidently a subject of great importance.

The various uses of coal by engineers enumerated.

Coal for generating steam.

Coal varies in evaporating power.

For the melting of ores and metals, the comparative values of different kinds of coals cannot be so easily defined as in either water evaporation or gas-making. Although the strength and other qualities of iron and steel which determine their value vary greatly, the chemical differences which produce these qualities are minute, and depend to a considerable extent on the qualities of the fuel with which the metals are brought into contact. Coal has usually to be coked before it can be used with advantage in a blast furnace or foundry

Coal used for melting ores and metals.

Coking of coal.

See page 128

cupola, and its suitability for this process, as well as its calorific or melting power, goes far to determine its value. All coal and coke contain sulphur, and for most metallurgic processes the degree of purity in this respect is of great importance. The suitability of the coal depends also on the exact nature of the melting process, the kind of furnace, and the strength of the blast.

Freedom from sulphur.

Coal for gas-making.

See CANNEL, *page 121.*

For the production of illuminating gas, the calorific power of coal is not of primary consequence; the volatile matter contained by the coal, and which is given out in a profitable form as gas, being the measure of value. English coals yield from 7,000 to 14,000 feet of gas per ton, and have a value for gas-making accordingly, although of course the purity and illuminating power, and the amount of the residual coke, are also to be taken into account.

Classification of coal difficult.

Bituminous coal.

It is not possible to classify exactly the different kinds of coal, nor indeed can it be positively determined what minerals may be included in the generic appellation coal. The various kinds found in the United Kingdom may, however, be broadly divided into *Bituminous*, *Anthracite*, and *Cannel*, though it would be more correct to call many of the kinds semi-bituminous or semi-anthracite. *Bituminous* coal, which is the most abundant in Great Britain, and which may for the present purpose be said to include all coal not in the other two classes, is found in almost all the coal districts, and although it varies very much, it is used for all the purposes named above. It is from a particular kind of bituminous coal, only found in a few districts, that most of the coke used in iron-smelting is made.

See COKE, *page 127.*

Anthracite coal.

American anthracite.

Is hard and requires strong draught.

But has little smoke.

Anthracite coal is smokeless, and is useful for special purposes, but such anthracite coal as is found in the United States is not by English users considered so suitable as English coal for any of the purposes enumerated on page 119. But in America it is used as fuel for smelting iron, for which purpose its hardness renders it suitable without coking. When used for other purposes, where there is no blast, special arrangements for creating a strong draught are necessary, but when once well kindled it will, if the draught be regulated, give economical results. The smokelessness of anthracite coal and its freedom from dust are advantages which go far to compensate for drawbacks in other respects. Much of the steam coal of South Wales may be classed as semi-anthracite, and is particularly valuable for use in steam-boilers, as in proportion to its bulk or weight it will evaporate more water than any other kind. It has its highest value in steam-ships, where economy of

Welsh coal for use in steam-ships.

See pages 119 & 125.

stowage space is important. As, however, it is slower of combustion than the more bituminous coal, and requires a strong draught, in some cases it is found expedient to mix it with the latter to assist combustion. Owing to the small quantity of sulphur in semi-anthracite coal, it is useful as fuel for making certain kinds of iron and steel, its hardness being no obstacle to its use where combustion is stimulated by the blast of a furnace. The Welsh anthracite is used also on river steamers in England because of its smokelessness, and is for the same reason used for boiler furnaces, bakers' ovens, and other purposes in large towns where there are municipal regulations against smoke. Its freedom from sulphur causes it to be used as the best fuel in malt-kilns. On the other hand, as it evolves, when carbonized, but little volatile matter, it has hardly any value compared with other English coal for gas-making.

Mixed coal.

Semi-anthracite free from sulphur.

And from smoke.

Different uses.

Not suitable for gas-making.

Cannel coal, well known by its hard smooth texture, and best obtained in the districts of Wigan and Newcastle, and the Boghead coal of similar kind found in some parts of Scotland, have their highest value for gas-making, as they will give out gas about 20 per cent more in quantity than that from bituminous coal, and of higher illuminating power.

Cannel coal.

Where found.

Is best for gas-making.

Patent fuel, which is made principally at coal-shipping ports, is composed of the small slack and dust which are screened from the larger coal, compressed with some bituminous compound by hydraulic power into rectangular blocks. This coal generally sells for about one shilling per ton more than the ordinary coal, and it has the advantage of stowing compactly, and of being easily handled. In England its use is confined almost entirely to steam-ships, and, if compared with ordinary coal for such purposes, it is generally considered slightly inferior to coal from the same mine, the convenience in stowage being its chief recommendation. Engineers, however, are not agreed on this subject. Patent fuel is largely used in the locomotives of French and Belgian railways; and on a few of the American railways, patent fuel made from the dust of anthracite coal is used.

Patent fuel.

How made.

Compact for stowage.

Used in steam-ships.

And as fuel for locomotives.

Coal is exported in large quantities from England to Continental countries for almost all the purposes—smelting, gas-making, steam-generating—to which such fuel is applied, and no English export duty nor legislative restriction of any kind hinders the foreign purchaser who finds he can buy in England to advantage; and many of the foreign countries which impose high duties on English manufactures, admit coal almost entirely free of duty as an essential aid to their own

Export of coal.

Free from duty.

industries. It is not the mere abundance of coal in England which renders it so cheap for use abroad, but its contiguity to the sea-board and the unrivalled facilities for shipment and cheap sea-carriage which are available. Thus, it is cheaper to purchase English coal and carry it across the ocean to South America for use there in steamers and for gas-making, than to dig it from the Brazilian mines, and carry it one-hundredth part of the distance along bad roads. So, also, large quantities of English coal are taken annually to India, for use there on the railways and steam-ships; for although coal abounds in India, and may in some districts even be bought at low prices with moderate rates for carriage, yet it is often dearer than imported coal when measured by quality as well as by price.

Cheap sea-carriage. *See page 36.*

Renders coal cheap abroad.

English coal in India.

The principal coal-shipping ports in Great Britain are Newcastle-on-Tyne, which is so near to the famous Northumberland collieries that much of the coal is put directly on board the ships from the colliery wagons, with but trifling cost of railway transit; Sunderland, at the mouth of the Wear, and Hartlepool, which are equally well situated for the Durham coal-fields and the famous Durham coke; the Bristol Channel ports of Cardiff, Swansea, Llanelly, and Newport, where the steam coal of South Wales is shipped, and where the pits are situated within three to twenty miles of the sea; Liverpool, where Lancashire and Yorkshire coal is sent for export; Birkenhead (included in the port of Liverpool), to which the railways from the Cheshire and North Wales collieries converge; Hull and Grimsby, the principal ports from which the steam coal known as South Yorkshire and the Barnsley thick-seam is despatched; Goole, where also much Yorkshire coal is shipped; Glasgow, Greenock, Leith, and Granton, the chief ports for the Glasgow hard splint coal; and Boness on the Forth, where the mines of cannel coal are actually by and under the sea.

Coal-shipping ports in England.

In Wales.

In Scotland.

The total export from Great Britain during the year 1878 reached 15¾ million tons, of which, approximately, the following proportions, were shipped from the above districts:—

Total quantity exported in 1878.

4	million tons	from the	Tyne.
5½	"	"	Bristol Channel ports.
1¾	"	"	Sunderland and Hartlepool.
1	"	"	Hull and other Yorkshire ports.
¾	"	"	Liverpool and adjoining ports.
2	"	"	Scotland.

Proportion from each district.

Patent fuel from all parts 222,000 tons.

The above quantities are exclusive of the coal and patent fuel taken in the bunkers of foreign-going steamers for use during the voyage, and also of coal carried coastwise. **Exclusive of bunker coal.**

At the principal coal-shipping ports the facilities for loading vessels are very complete, as, by means of well-arranged docks, railways, inclined planes, hoists, cranes, and shoots, the ships are not only loaded expeditiously and cheaply, but with the minimum damage to the coal. Coal is necessarily broken during the process of shipment, but great ingenuity has been exercised to prevent it. Instead of allowing the coal to fall from the shoots a considerable distance to the hold, the shoots are in some cases adjusted to allow of a moderate fall at all levels of the tide or cargo; and in others the coal is lowered in boxes or wagons, which are emptied only when they reach the accumulating heap of coal in the hold. If all the elements of expense, including that of demurrage on vessels lying idle, be taken into account, it will be found that the cost of shipment is represented by pence per ton, where formerly shillings were expended. **Facilities for shipment.** *See* CRANES. **Coal broken in loading.** **Precautions to avoid breakage.** **Saving in expense.**

Coal broken in shipment is not only rendered less valuable, but becomes specially liable to spontaneous combustion and gas explosion during the voyage. The large number of coal-laden vessels lost annually from this cause has had the effect of raising the rates of insurance, and even of disinclining some shipowners from coal cargoes altogether. Much stress has been laid upon the importance of ventilating the cargo, and to the neglect of this precaution most of the losses have been attributed. But by careful and exhaustive inquiry it has been ascertained that by ventilating the mass of the cargo, combustion is promoted, as the air so admitted makes the gases more inflammable. The precautions really necessary for the safety of coal cargoes are: **Risk of ignition and explosion on shipboard.** **Ventilation of coal in the hold.** **Erroneous precautions.**

Proper precautions.

1. The avoiding of certain descriptions of coal, which are intrinsically dangerous for long voyages.

2. The prevention of breakage in the passage of the coal from the pit to the ship's hold.

3. Care in avoiding the shipment while in a wet condition of coals containing a large quantity of pyrites (all coal contains more or less.)

4. The ventilation of the surface of the coal in the hold so as to allow the escape of gas, while avoiding the admittance of atmospheric air to the mass of the coal.

Where the expense of carriage from the collieries to the place of

Choice of coal depends on locality.

consumption differs very much for different kinds of coal, it is not always advantageous to buy the better kinds; and at each place, according to its locality and the cost of carriage from the various collieries, must the choice be made. Economy is sought sometimes by mixing different kinds of coal together. Thus at gas-works, in the vicinity of which bituminous coal is obtained, the engineer will use cannel sparingly, and will probably arrive by experience at a combination of the two kinds, which, as regards the outlay for coal and the quantity and quality of the gas, will give the most advantageous results. So also in steam-ships, if loading at Newcastle or South Wales, a mixture of different local kinds may be selected, or at a coaling station a mixture of Newcastle and Welsh coal may recommend itself as cheapest; the question being determined by the suitability of the furnaces for particular kinds, the importance of maintaining high speed, and other circumstances. But for use in a foreign country, far from any source of supply, it may be stated as an almost invariable rule that the best coal of its kind should be imported. The freight and charges may amount to two or three times the first price of the coal, and it is obviously advantageous under such circumstances to purchase only the best. Coal, which will evaporate 10 per cent. more water than another kind, or which will produce 10 per cent. more gas, will have found in England its level in price and be 10 per cent. dearer. If this 10 per cent. represents at the port of shipment 1s. per ton difference in price and the cost of freight is double the price of the coal, this superiority which has been purchased for 1s. is at the port of arrival equal to 3s. per ton. For the same reasons the coal should be shipped in the best order, and in addition to the usual screening at the colliery, which is considered necessary for home consumption, a small extra price is sometimes paid at Welsh ports (though hardly ever on the Tyne) for a second screening at the place of shipment. But, though this extra screening may be of advantage to coal shipped as merchandize and to be discharged and stored for re-sale, the expense is of doubtful expediency for coal to be consumed on board, and especially if the coal be hard.

Cheapness sought by mixing coal. *See* GAS-WORKS *in Part I.*

Instances.

Choice for export.

The best is cheapest.

Freight and charges common to all.

Screening of coal.

Double screening.

Where expedient.

Suitability of coal to bear carriage and storing.

In selecting coal for use abroad, not only its quality for the ultimate purpose has to be considered, but its fitness for sea-carriage, the stowage-space it will occupy, and its suitability for storing. Some coal is softer or more friable than others; and the loading, the rolling of the ship, and the discharging at the port of arrival together,

Friable coal.

break it up and reduce its value. And, as coals differ considerably in the stowage-space they occupy, a ship of certain capacity will take more of one kind than another, the differences between various kinds being—in proportion to their weight—as much as 20 per cent. Some of the Welsh coals occupy only 38 cubic feet to the ton, but shippers generally reckon that a space of from 42 to 45 cubic feet is occupied by each ton of coals, and it is not till a ton can be stowed into 40 cubic feet that the ship's space is most profitably occupied. Shipowners naturally prefer the heavier coals, which, when all the space is occupied, will have brought the vessel down to its proper water-line and afford the greatest freight remuneration. Gas coals are, as a rule, heavier than steam coals. Coal is liable to a loss of effective power by voyaging and by storage in hot climates; and as the deterioration varies with the kind of coal, it is important to take this also into account. For instance, the Welsh steam coal, which may be best for immediate use on board a steamer, will lose more of its calorific power by storage in a hot climate than will bituminous coal, and therefore the supplies sent to certain coaling-stations are often selected from the more bituminous of the Welsh coals, which are not of the highest value at the port of shipment.

Space occupied in stowage varies.

See page 35.

Deterioration by climate and storing.

Coal selected accordingly.

Where the place of consumption is far from the source of supply, it is expedient to keep a sufficient stock in advance as a safeguard against possible delays in the arrival of a fresh supply. This course is especially necessary where no other fuel can be obtained to supply a temporary want; therefore, at important steamship-coaling-stations and at foreign gas-works, coal is generally stored in large quantities; and at most foreign ports and coaling stations, there are merchants who keep a stock of coal to sell to all comers.

Importance of sufficient stock.

As for steam-ships and gas-making.

As coal is constantly fluctuating in price, and occasionally is subject to great variations, the trade, for those who are obliged to buy in advance, is somewhat speculative; but apart from such fluctuations, and equally important to the consumer abroad, are the variations in the cost of sea-carriage. Some of the causes which determine freight have been already alluded to, and the purchaser of coal for export has to watch these closely. The naval authorities, steamship owners, foreign railway and gas companies, and others abroad who require English coal, make bargains for several months or sometimes even years in advance; and both in regard to the price at the port of shipment and the cost of freight, the purchaser, the coal proprietor, and the ship-owner alike have to estimate the probable prices during the

Fluctuations in price.

And in cost of freight.

See page 36.

Contracts in advance.

period, and in the terms of their bargain discount the future accordingly. But there are constantly occurring opportunities of shipping coal profitably. As at those foreign ports to which English ships are sent coal is always a saleable commodity, it is a common practice among ship-owners, ship-brokers, or merchants, when there is a lack of more profitable cargo, to fill up the vacant space in the hold with coal, in the certainty that, whatever the current price of coal at the port of discharge may be, some profit or freight remuneration will remain beyond the cost of the coal in England, which will be better than having taken ballast. Small quantities of from 20 to 100 tons are often taken in this way; but in such cases friable coal, such as was referred to on page 124, should be specially avoided, as with other cargo placed above, it is specially likely to arrive at its destination broken and ground to pieces. Indeed the liability to damage in shipment, transit, and unloading are so great that part cargoes of coal always fetch a less price per ton at the port of arrival than entire cargoes of coal. Often, also, when there is a likelihood of profitable homeward cargoes, merchants, in the absence ot any special demand for other commodities, will send out as a venture a ship laden with coal; and the agents in England of coal users abroad are generally empowered to charter such ships whenever the total price—cost, freight, and insurance—can be brought below a certain agreed sum.

Speculative shipments.

Small quantities as ballast cargoes.

Part cargoes fetch only low prices.

In establishing a line of steam-ships or a gas-works, or in conducting any enterprise in a foreign country which involves great consumption of coal, the certainty of a supply at a cost which may be approximately estimated beforehand, is a question of the first importance. When English coal is required, and the port of arrival is well frequented, the local conditions which may affect the freight or terms of chartering are sure to be known by those concerned in England; but if the port is a new one, or only suitable for certain kinds of vessels, full particulars concerning harbour accommodation, dues, facilities for discharge, and chance of return cargo, are necessary to allow of a vessel being chartered in England on favourable terms.

Cost of coal important in many undertakings.

Coal-ship charters.

Rates of freight, how determined.

Coals have been occasionally, in Newcastle and neighbouring ports, sold by the "keel" of 424 cwt., but are now (1880) sold there as elsewhere, by the ton of 2,240 lbs.; and the seller is by the custom of the trade supposed to give slightly in excess, so as to cover errors in weighing. In the United States the ton of 2,000 lbs. is usually adopted. The coal is rarely weighed at the port of discharge (the tonnage and draught of the vessel giving a near indication of the weight), the buyer

Measure of weight and value.

Weighing of coal.

generally agreeing to take the bill-of-lading quantity as correct without weighing, subject sometimes to a deduction to cover mistakes. The amount to be deducted is a matter of bargain, 2 per cent. being a usual allowance. In other cases, captains will not sign bills-of-lading for precise quantities which they have not been able to verify, but will only sign for "quantity unknown, all in the ship to be delivered." Coal is often taken improperly from the cargo during the voyage for use in cooking or for other purposes, and a store is even put by for the return voyage. It is, therefore, generally stipulated that the captain shall buy a certain quantity of the cargo at an agreed price, or that the ship shall carry a specified quantity for her own consumption stowed apart from the general cargo, and in the case of steamers, a special agreement is made concerning the bunker coal.

Allowances for mistakes.

Coal for ship's use allowed for.

When coal is to be purchased in England for use in a foreign country, all the circumstances of the case should be communicated to those who have to choose the coal. If for generating steam, a description of the boiler, furnaces, fire-bars, and flues; if for gas, the kind and size of retorts, methods of purification adopted, the quantity of gas required from a specified number of retorts in a given time, and the conditions in regard to illuminating power and purity which are imposed; if for smelting ore or melting metals, an analysis of the ore or metal should be furnished, with a description of the furnace and the blast; if for puddling, steel-making, or other metallurgical operations, the nature of the material to be treated, the kind of apparatus, the process, and the results desired should be given. Whatever the use to which the coal is to be applied, it is important to have a description, with prices, of any local fuel available, so that not only may the expediency of mixing the local and imported coal be considered, and the selection of the latter be modified to suit such a combination, but also that the total outlay for purchase, carriage, and insurance may be set against the cost of local fuel, and a comparative measure of value arrived at.

Circumstances on which choice of coal depends.

Comparison with other coal and local fuel.

Coke was first introduced as a substitute for charcoal in the smelting of iron, for which purpose most English coal is unsuitable, because it swells and cakes together, prevents the regular descent of the ore, and does not allow the free passage of the blast. These conditions apply particularly to the rich bituminous coals which, when coked, are the best for smelting; and the superiority of coke to coal justifies the expense of the intermediary process of making it.

Coke.

Why and where used.

As superior to coal.

Various kinds of coke.

Gas-coke inferior. *See* GAS-WORKS *in Part I.*

How made.

Coke is of various kinds, and there are numerous methods of making it; but it may be broadly divided into two classes, *i.e.*, coke made at gas-works, where it is the residuum of coal after the main object of extracting illuminating gas has been accomplished; and coke made directly for its own sake. In the first case, the coal is generally selected for the quantity and quality of illuminating gas which can be obtained: the process of coking is also directed towards these results; and the coke is less in quantity and value than that produced from coal selected purposely for coke-making. For extracting gas, coal is placed in closed retorts, to which heat is applied outside; and the residual coke is light and quite unsuitable for the smelting of iron-stone or the re-melting of iron in the foundry, for it is not strong enough to bear without crumbling either the burden in the furnace or the intense blast by which the fire is stimulated. Such coke is used as fuel for open smithy fires, for the heating of buildings, often also for domestic purposes, and is largely consumed in towns and places where smoke is prohibited. In London enormous quantities of coke are made at the various gas-works in and about the metropolis, and more than half of it is used in the manufacture of Portland cement. The value of gas-coke is determined by that of other fuel in the locality, with which it has often a forced competition, and in districts where coal is cheap, it has even happened that the coke has been disposed of only by giving part of it gratis to whoever would fetch it from the gas-works.

Unsuitable for melting-furnaces.

Uses for gas coke.

See PORTLAND CEMENT.

Value depends on that of other fuel.

Qualities of coke for iron and steel making.

The exigencies of smelting, and the scientific precision with which all the operations in iron and steel-making are conducted, have elucidated the qualities which are necessary; not only strength and combustibility being important qualities, but freedom from impurities, particularly sulphur, which has an ill effect upon the metal brought in contact with it. It is usual for certain purposes to improve coke by crushing it and—if the coke be of inferior quality in this respect—washing it with water, the latter process ridding it of much of the sulphur it possesses. In coal suited for the production of coke a combination of qualities is needed not often met with, and in the United Kingdom such coal is obtained only in the Durham districts, where much of the rich bituminous coal affords good coke, and in a certain limited part of the South Wales district, where a peculiar bituminous anthracite is found. Coke is made in other coal and iron districts, but though occasionally used for smelting where, because of long carriage, the better coke is expensive, its use is as far as possible

Sulphur in coke.

Durham coke.

Welsh coke.

Uses for other coke.

confined to metallurgic processes other than melting, and not requiring a strong blast.

The various qualities of coke are mainly exhibited in difference of density, colour, and combustibility. According to the kind of coal and manner of coking, the quantity, by weight, of coke produced ranges from 60 to 80 per cent. of the coal treated. As an average, it may be stated that coal when coked loses one-fourth in weight and gains one-fourth in bulk. These proportions do not apply to gas coke made from cannel, which is much lighter.

Differences of kind.

Weight and bulk.

From 1 to 1¼ tons of coke are consumed in the production of 1 ton of pig-iron from ore, and in a foundry cupola from 150 lbs. to 350 lbs. of coke is necessary for re-melting 1 ton of pig-iron, the exact quantity being determined by the quality of the coke, that of the ore or iron, the nature of the blast, and the skill in the arrangement and management of the furnace or cupola.

Quantity of coke needed to smelt and melt iron.

Coke was at one time largely used in the furnaces of locomotives, as it afforded a more concentrated heat than coal, and was much more easily managed. It has been found, however, that by suitable fire-boxes and by more continuous and careful stoking, coal, which is cheaper than coke, can be used with advantage, while the steam blast in the chimney destroys most of the black smoke which is caused by the use of coal. Many of the railways which established coking-ovens have abandoned them, and the quantity (1880) used in locomotives is very small, as compared with coal.

Coke as fuel for locomotives.

Now superseded by coal.

Coke is almost always sold by weight; but as, owing to its extreme porosity, it will absorb much moisture, the quantity of water it may contain is an important consideration in determining its value when weighed. Coke is occasionally sold by measure of bulk, the chaldron of 36 bushels being the unit employed in England; from 13 to 14 cwt. per chaldron being approximately the weight of good coke, the density or weight going far to determine the value of the coke as fuel for melting. Durham coke sells for about 16s. per ton, when the coal from which it is made costs 7s.; but the price fluctuates with the briskness of the iron and the steel trades; and in busy times prices are proportionately higher, and the profits of coke-burning greater.

Coke sold by weight.

Sold by bulk.

Price of Durham coke.

Considerable quantities of coke are exported to Spain, Russia, and other Continental ports for foundry use, and also for smelting ore; for though smelting is seldom carried on with profit, except in countries where coal is plentiful and coke can be produced near the

Export of coke.

collieries or furnaces, coke is occasionally imported for the smelting of local ore in countries where the protective duties hinder the competition of iron made elsewhere under more natural and more favourable conditions. The export of coke beyond Europe is very small, India and South America taking the most, for use in the melting of foundry-iron and for other purposes in engineering factories. The total shipments of coke only reached 274,000 tons in 1878, a very small quantity compared with that of coal.

Quantity small.

See page 122.

Sea freight of coke.

The sea freight of coke is charged by the ton of 20 cwt., but the rates are higher than for coal, because of the greater space occupied. But there is no fixed proportion between the weight of coal and coke occupying the same space; for coal varies much, and coke much more. The "keel" of coke used sometimes, though now (1880) very rarely, as a measure of freight on the Tyne, is by custom accepted as equal to 11 tons, while the keel of coal equals 21⅛ tons.

Weight and measurement of coke.

Pig-iron.

Pig-iron, as the immediate product of the ore-smelting furnace, is iron in the first stage of manufacture, rolled or malleable iron being obtained by after processes. There are great differences in pig-iron, caused primarily by the quality of the ore, and then by the kind of fuel and the mode of smelting; and certain districts have, because of the ore and fuel there obtainable, and the methods of making, become associated with certain kinds of pig-iron. The principal difference in process is that between the cold-blast and the hot-blast iron. By the latter, much less coal, even allowing for that consumed in heating the blast, is required to melt the iron, and the melting is much quicker. Moreover, by the hot blast, more iron is obtained from the ore than is possible with the cold blast. Except for special purposes, such as the making of high-class malleable iron of the Lowmoor kind and for certain kinds of castings, the cold blast is seldom used, and probably not more than three per cent. of the blast furnaces in the United Kingdom are so worked, for the superiority over good hot blast-iron is too slight to justify the much greater cost of production. But although the hot blast is applied so skilfully as to have overcome prejudices which at first existed against it, and though high-quality pig-iron can be produced by it from suitable ore, the extreme power of the hot blast when applied to inferior ore, undoubtedly produces iron mingled with impurities which the cold blast would have left behind in the form of dross and slag.

Varieties in kind.

Cold-blast and hot-blast iron.

Small proportion of cold blast.

Inferior iron produced by hot blast.

Iron districts.

The best irons are made in Staffordshire, Derbyshire, South York-

shire, Lancashire, and Lanarkshire, while the greatest quantity is produced in and around the Middlesborough or Cleveland district. The name of the district is not, however, so sure a guide to quality as formerly, for the exhaustion of mines in some places, the opening out of new mines, the facilities for carriage from one to another, and the demand for low-priced castings, have entirely altered the traditional customs of the iron trade. In South Staffordshire, which formerly was the principal centre, many of the mines have been exhausted or so far worked out that the cost of getting the ore is too expensive, and inferior ores are brought from other counties to mix with the local sorts. In Scotland, also, although the reputation of particular kinds or brands has been generally maintained, the relative excellence of different brands varies from time to time. The constituent parts of the ore are liable to variation as mines are further explored or new mines become associated with existing brands; and as, moreover, the management of the blast-furnaces is occasionally modified, such changes are accounted for. The greatest innovation in the Scotch districts is the import thither of the cheaper Cleveland iron, this commerce having (1880) attained enormous proportions. On the other hand, Scotch, hæmatite, and other high-quality irons are imported into the Cleveland district to mix with the local iron when high tests are demanded. Large quantities of Spanish ore are imported into England for mixing with local ores in steel-making.

Local qualities altered.

Mines exhausted.

Mixture of ores.

Iron varies though brand remains.

Cleveland iron mixed with Scotch.

The iron-making advantages in Cleveland are the abundance of the ore, the nature of the deposit which cheapens the cost of getting, and the close contiguity of coal and limestone. These advantages were developed by the skilful application of the hot blast; but the trade could never have attained its subsequent proportions, had it not been also for the unequalled facilities for shipment; this combination being more favourable than that of any other iron-making district in the world. Cleveland iron is generally sold at a much lower price than that from other of the principal districts, and therefore commands a vast sale, notwithstanding its moderate quality; this lower price being remunerative to the makers, because it is all applicable to the expenses of manufacture, without deduction for inland carriage.

Local advantages of Cleveland.

Shipping facilities.

Iron sold at low prices.

The best of the Scotch irons are distinguished by fineness of texture, the metal setting when cold into small crystals, which favour the casting in the foundry of thin and sharply-defined forms, difficult of attainment with the iron from other districts. Thin rain-water gutters, fire-ranges, and light ornamental castings are for these reasons

Quality of Scotch iron.

Produces fine castings.

made with advantage in Scotland; and Scotch pig-iron is sent to all parts of the island for mixing with local kinds. Much skill has been

Castings made from mixed iron.

exercised by the Scotch founders in making castings of the accustomed kind and form from the cheaper mixture of Cleveland with Scotch iron, but castings so made have not the quality which their appearance may indicate. Tenacity and toughness are the qualities most needed in cast-iron, but for a large proportion of iron castings

Quality often disregarded.

neither superior strength nor fineness is deemed of great importance by purchasers, because the size and thickness of the castings may be so far in excess of what would be necessary to resist (with a considerable margin of safety) the strains which will come upon them, that the inferior quality is never detected or is considered of no consequence; sometimes, also, secondary reasons are the cause. Archi-

Castings made thick rather than good.

tectural outline, the difficulty of casting large thin pieces, a thickness to allow for safety in carriage or for the wasting by rust are, rather than any precise strain to be borne, the circumstances which often guide the designer, who gives more thickness than would be necessary for the ultimate purpose if good quality iron were used. For castings exposed only to compression, the strength in this respect of even the commonest pig-iron may be sufficient. And even in such castings as girders and long columns, exposed to transverse strains, architects and engineers often consider it easier to allow ample form and thickness than to incur the trouble and expense of tests necessary to ensure a good quality. It is to this indifference, and to the measur-

Deterioration of English iron.

ing of cheapness by price alone, that the degradation of quality which has undoubtedly taken place in many kinds of English pig-iron during the twenty years ending 1880 is mainly due. For the parts of engines or machinery, for pipes subject to high pressure, and for other uses where

See PIPES, *Chap. XX.*

the iron is exposed to active and percussive strains, the higher qualities become of vital consequence. For purposes such as these, if there

Tenacity of iron.

is any doubt of the quality, the tenacity or resistance to tension of the iron should be tested. From 5 to 14 tons per square inch of sectional area are the wide limits of strain which different kinds of cast-iron will endure. Resistance beyond 8 tons may be considered as exceptional, it being obtained by special methods for particular purposes, such as for guns. For the iron of commerce a tenacity of from 5 to 8 tons is usual, and some strain between 6 and 7 tons is often specified as a minimum, and up to a strain of 2½ tons, there should be no loss of elasticity, *i.e.*, of the power of recovery to the original form when the strain is removed. A working strain of 2 tons

for iron of ordinary quality is safe for steady loads, but where the iron will be subjected to percussion, only one ton should be allowed. A method more often adopted by engineers for testing cast-iron, is to try it in the form of a girder or beam, from the centre of which is suspended a weight, the load which is borne before fracture denoting the tenacity and toughness. A solid bar of rectangular section 2 inches deep, 1 inch wide, and 3 feet 6 inches long, is generally employed, a standard size being convenient for comparison. The bar is laid on bearings 3 feet apart and loaded in the middle till it breaks; from 22 to 36 cwt. expressing the wide range of quality in British-made irons; a strength beyond 32 cwt., though sometimes obtained, being outside the ordinary range of the irons of commerce. The lower load generally indicates that the iron has been made from one inferior ore, or that there has been a large admixture of cinder iron, puddling-furnace slag, or similar refuse, which by the aid of the hot blast can be converted into so-called iron. A breaking load of 25 cwt. can be usually endured by bars made from ordinary pig-iron, and this quality is sufficient for thick columns, short stancheons, or similar castings exposed mostly to compression. A test load of 28 cwt. is often adopted by engineers, because while it ensures a superior quality it is not so high as to limit greatly the competition in the supply. There are few kinds of hot-blast pig-iron made from any one kind of ore, which when re-cast will endure 28 cwt. on the test bar, but by the judicious mixture of two or more kinds 30 cwt. may be attained; and this load is often specified for high-pressure pipes or machinery castings. Even higher tests may be obtained, but are seldom demanded except for special purposes, as it generally costs more than the mere comparison by extra strength would justify.

Method of testing.

Cinder iron.

The beam test.

See PIPES, *Chap.* XX.

Exceptionally high tests.

But while for a home trade, the cheapest pig-iron may find the readiest sale, the conditions are greatly altered when pig-iron is bought for export to distant countries. Cleveland pig-iron is exported in large quantities from England to the Continent for manufacture into rolled iron and hæmatite pig-iron for steel-making, but Scotch iron is generally chosen for export for foundry purposes to countries beyond Europe. The choice of pig-iron for export is determined greatly by the contiguity of particular districts to the port of shipment, and it is because the cost of inland carriage bears a high proportion to the value of the iron and to the sea freight, that the products of the blast-furnaces in the Midland districts cannot compete with

Pig-iron for export.

Foundry iron.

Inland-made iron burdened with carriage to port.

iron made on the sea-board. This limits greatly the export of pig-iron from Staffordshire, Derbyshire, and South Yorkshire, and gives a corresponding advantage to the Cleveland and Scotch irons. As, however, the cost of freight, duty, and other charges in the importing country are assessed by weight, and as these expenses are in the aggregate great in proportion to the first cost of so cheap a commodity as pig-iron, it is evidently undesirable to attempt a saving by choosing an inferior kind, unless—for the purpose in view—the quality is absolutely of no importance. Thus, while it would be wasteful to buy high-quality pig-iron for casting into cannon-balls or fire-bars, it is generally profitable to select a good quality for engineers' foundry purposes. Scotch pig-iron is frequently imported into foreign countries to mix with native iron of inferior quality, and also in many cases with scrap cast-iron. The quality of these local irons of course goes far to determine the kind of imported iron to be selected. The kind of castings to be made, the cost of freight, the duty, and how it is assessed, are also important incidents to be considered.

Freight charges common to all kinds.

Best is cheapest.

Imported iron mixed with scrap or native iron.

Engineers and iron-founders who import pig-iron naturally acquire by experience a knowledge of their comparative values; and those who are thus informed regularly specify the brands which they consider will suit them best. But for the reasons already stated, the quality of iron produced in any particular district is liable to variation, and a knowledge of these changes and the ability to take advantage of them, are niceties which pertain to those who confine themselves especially to this one branch of the iron trade.

Special kinds found suitable.

Hæmatite iron.

Ingot-moulds.

Pig-iron of special quality, such as the hæmatite from Cumberland, is exported for steel-making; and this metal is sometimes sent out in the form of ingot-moulds to steel works, because of its ultimate value as scrap-iron for remelting when it has served its first purpose.

Steamers for carrying iron.

Iron carried as ballast cargo.

Iron and coal together.

See page 126.

Complete cargoes of pig-iron are conveyed coastwise and to Continental ports; and powerful, strongly-built steamers are specially constructed for carrying such dead-weight cargoes; while for ocean voyages, sailing vessels are most often employed. But an entire cargo of pig-iron involves high rates of insurance, especially in winter seasons. Pig-iron is often utilized as weight or ballast cargo at the bottom of a vessel which is to carry lighter merchandise above, and small quantities of 10 to 50 tons are often shipped to complete or adjust a miscellaneous cargo. A shipload composed of pig-iron at the bottom, and coal or coke above, is not uncommon, especially in sailing vessels.

Weight of iron pigs.

Pigs of iron weigh from 80 lbs. to 112 lbs. each, and, as preparatory to melting, or for convenience in inland carriage, can be broken by a sharp blow with a sledge hammer, a small steam-hammer being sometimes provided for the purpose where the quantity is large and frequent. For making into malleable cast-iron and other purposes where the melting is performed in crucibles, light pigs of from 20 lbs. to 60 lbs. are usual.

Rolled iron.

Rolled iron (called malleable iron in some districts) as used by engineers may be divided into the following classes:—Rails, plates, sheets, bars, L bars, T bars, channel ⊔ bars, I joists, Z iron, bulb T iron, hoops; numerous other special forms of iron being made for various purposes. The natural tendency of trades towards subdivision takes effect in the iron trade as elsewhere, and each of the classes enumerated above forms a specialty of manufacture separate from the other; for although certain makers do at the same works roll bars and plates, or joists and L irons, yet, owing to various economical reasons, such as the contiguity of suitable materials, facilities for delivery to the consumer, and other circumstances, the great bulk of each class is made at those works where little else than one or two of the various classes are produced.

Subdivisions of manufacture.

Changes in the iron trade.

The trade has undergone great changes since 1860, partly owing to alterations or improvements in the processes of manufacture, but mainly to the vast increase in the number of rolling-mills, and the new localities into which the trade has spread. The ironworks which have been established in Germany, France, and Belgium, not only produce what had formerly to be imported thither from England, but compete with England in supplying other countries. The trade-marks or brands of old-established makers in England still however maintain their reputation, and—by the protection they afford to purchasers, especially to those abroad, who have found by experience what quality is associated with these brands—command a higher price than iron unmarked or with brands of less repute. This difference in price is, in effect, a bonus or a premium of insurance paid by the purchaser to avoid doubt as to what he is buying. But although a preference is still shown for the iron of particular makers, the localities having traditional reputation can no longer maintain as exclusively as formerly the monopoly they have had in the manufacture of iron, and the condition of quality as ascertained by specific tests tends to put different makers on a level. Terms such as "Best," "Best

New ironworks established on the Continent.

Trade-marks on iron.

See page 18.

Old monopolies superseded.

Definition of quality.

Best," "Best Staffordshire," though they may convey a definition of quality to those immediately concerned, and in regard to the iron supplied by well-known makers, are not accepted as sufficient by purchasers generally.

"Extras" on rolled iron.

Current prices conditional on size and weight of pieces.

Another condition of the trade in rolled iron, which is becoming gradually altered, is that of "extras." The current rates for rolled iron are based on certain accustomed conditions as to shape, dimensions, and weight of each piece. If anything outside or different from these conditions is required by the purchaser, extra prices are charged, which in some cases bear a high proportion to the nominal cost of the iron, and indeed in some instances the profit of the maker lies in these "extras." Makers have each their own rules, and there is a general uniformity throughout each district, though the rules in the different districts such as "Staffordshire" or "North Country" do not exactly coincide. As improved or more powerful machinery is established, the limits within which the ordinary current prices prevail are extended, and in several instances Continental makers have led the way in such concessions. The rules which apply in regard to extras are approximately stated on pages 143 to 150 against each kind of iron, but these rules are subject to variation in special cases, for although price-lists are printed and rules established for extras, an ironmaster will not always offer such low rates in a price-current or in answer to a general inquiry, as he will when he has presented to him a specification containing the sizes, quantities, and quality of iron actually required, with the periods and conditions of delivery and payment. He is then able to judge how far such an order will suit him at the particular time; and if it is suitable, or if it be a large order, or if his works are not well employed, then in many cases he will relax the ordinary rules, and offer prices more favourable to the purchaser than the mere current price and the nominal regulations as to extras would afford. It is the function of the iron merchant or factor to act upon these circumstances, and where a miscellaneous list of plates, bars, or other kinds of iron is presented by a purchaser, to divide it, and to obtain each kind from the manufacturer best able to supply it. An acquaintance with the capacity of different rolling-mills and with the special facilities of each for making large, long, small, or heavy pieces, often enables the factor to supply a purchaser more favourably than can any one manufacturer.

Limits extended or conditions relaxed.

Prices modified in favourable cases.

Rules as to extras.

Functions of iron merchants and factors.

Qualities of iron tested.

The tests of rolled iron are generally directed towards ascertaining tenacity, toughness, and elasticity. The tenacity or power of

resistance against tension is in England and the United States expressed in tons per square inch of sectional area of the piece operated on (on the Continent in kilogrammes per millimetre), and the different qualities of iron rolled in England have a minimum strength of 17 tons (26·7 kilogrammes per millimetre) and a maximum of 28 tons per square inch (44 kilogrammes per millimetre). The elastic limit of the iron is, however, that which determines its value for most purposes, as after the strain on iron passes beyond this point, permanent distortion and rapid extension takes place. The *limit of elasticity*, as it is called, is that amount of strain which the iron will undergo and still return to its original length when the strain is withdrawn; and this limit varies from 30 to 50 per cent. of the breaking strain. Thus, an iron bar which will withstand 22 tons per square inch before fracture, will, if it be of good quality, return to its original length after a strain of 10 or 11 tons has been imposed. After this limit of elasticity has been reached, what is called *permanent set* commences, and the iron does not return. The ductility of the iron is shown by its elongation under tension, and in a piece of iron pulled asunder this elongation varies from ½ in. to 2½ in. per foot. For ordinary structural purposes from ¾ to 1 in. elongation per foot denotes a suitable quality, but from iron piled, hammered, and rolled from good scrap-iron, or otherwise specially prepared, 1½ in. or more is obtainable. A greater ductility is not desirable for most purposes, and engineers generally prefer moderate ductility only, if they are assured that the iron is tough and elastic enough to withstand sudden or percussive strains without fracture. There are other methods of ascertaining the quality of the iron, the choice of test being determined by the purpose for which the iron is to be used. Thus for boilers, the toughness of the iron to endure bending and the freedom from flaws which exposure to heat would magnify, are the measure of value. A blacksmith will by breaking or bending iron soon ascertain whether it is suitable for his purpose, tests of this kind being sometimes specified either exclusively or in addition to tensile strains. The process of making horse-shoes is generally considered a fair test of quality, the bending, shearing, fullering (cutting close to the side), punching of nail-holes, and other manipulation of the iron revealing any hidden seams or cracks: the same result occurring in the numerous engineering forgings, where flanging, bending, and side cutting are necessary. It may be said that a tensile test unaccompanied by other conditions is misleading, as extreme strength in this respect may be obtained

Tensile strength, how measured.

Elastic limit in iron.

About one-half the breaking limit.

Ductility of iron.

Usual ductility.

Tests varied to suit purpose in view.

Blacksmith's tests.

Iron for horse-shoes.

Tensile tests misleading unless toughness ensured.

from brittle iron having a low elastic limit. Some engineers prefer to measure the ductility of rolled iron by the reduction of sectional area which the stretching causes at the place of fracture, and from 5 to 20 per cent. is the reduction from the original area which the different forms of iron rolled for structural purposes exhibit. In England, for the highest quality of structural ironwork, the following tests are specified; but in most cases, the test specified for L iron is considered sufficient for the bar-iron also.

Tests usual in England for structural iron.

See BRIDGES *in Part I.*

	Tension. Tons per sq. in.	Kilos. per sq. m.m.	Reduction of area at the place of fracture.
Bar-iron	24	37·7	20 per cent.
Angle-iron...	22	34·6	15 "
Plates (along the fibre)	21	33	10 "
Plates (across the fibre)	18	28·3	5 "

Obvious defects in iron.

There are some defects in rolled iron which are obvious on inspection: thus, cracks or seams may appear where the iron laminates, showing that, in the process of hammering and rolling, the various pieces in the original pile have not been properly welded, and that dirt or scale remains in the interstices. Black lines, which betoken seams in the iron, though unsuitable for polished work, or for the journals of shafting, are not necessarily a sign of bad quality, as strong, tough iron, if made from scrap, is liable to such appearances. Iron which looks clean and sound when cold, may reveal flaws and cracks when heated and twisted on the anvil. Some iron (often owing to the sulphur it contains) is "red-short," that is to say, it will not work well when hot, although when cold it may have a tough fibre. Cold-short iron (generally containing phosphorus) is brittle when cold, and though it may be worked successfully when hot by a skilful smith, it is useless for most engineering purposes.

Seams and imperfect welds.

Red-short iron.

Cold-short iron.

Export of iron.

It is not expedient, for reasons already adduced, to export iron of low quality; but except in special cases, such as when the cost of carriage, import duty, or other charges bears a high proportion to the purchase-money, and where, therefore, it is very important that the weight shall be as low as possible, it is not economical to demand a quality higher than is customary among makers of repute. If specially high qualities or exceptional guarantees are insisted on, the number of manufacturers who can and will compete is reduced, and the extra cost is more than proportionate to the advantage gained. In the case of wrought-iron for structures, such as bridges and roofs, it may be said broadly that if tests more rigorous than those tabulated above

Choice of quality.

Very high tests inexpedient.

be demanded, an extra price has to be paid, far greater than the extra advantage gained; but if only a higher breaking test be required, it can be satisfied at the expense of toughness; for, as just stated, by suitable material and methods of manufacture, a strong iron with a low elasticity may be produced as cheaply as iron of more moderate tensile strength having sufficient toughness. A skilful iron-maker can, if informed of the purpose for which the iron is required and the after treatment it is to bear, produce in many cases, even without extra cost, the quality which will meet these circumstances.

Strong iron without toughness

Iron made to suit purpose.

The relative cost and selling price of different kinds of rolled iron are determined by various circumstances. Where the demand for any one kind is very great, certain economies are obtainable, as a wholesale trade is always more cheaply managed than a retail trade. Rails are an obvious instance of this, and so long as thousands of rails precisely alike are ordered at one time, every incident in the manufacture can be arranged in the most economical manner.

Cost and selling price, how determined.

Some forms of iron demand a higher quality of raw material or more elaborate or expensive working than others. This is the case often with large thin sections. In other cases, although more trouble may have been bestowed on the working, the shape or thickness may not be favourable to good results. Thus, T bars, while about £1 per ton dearer than L bars, are not—the original material being equal—of such good quality, because the method of rolling T bars to give them their peculiar shape, is not so uniform or effective as in the case of L bars. The hammering and rolling necessary for plates is more expensive than the same process for ordinary bars, and the plates will not endure such high strains; and as also there is some waste in shearing the edges of the plates to a clean and regular edge, they cost about £1 per ton more than the bars.

Cost of process varies.

Examples.

Waste in cutting.

The larger proportion of rolled iron used by engineers is made to order for each particular case, and except for miscellaneous smithing purposes, it is seldom kept in stock, either by the maker of the iron or the user. The more usual sizes and sections of iron are kept in stock to some extent by makers and merchants, but as the length of bars, and the length and width of plates vary according to the required purpose, it is almost always necessary that the bars and plates taken from the stock must be cut to the desired sizes, this involving a waste very considerable in the case of large structures, and the cost of which has to be borne by the purchaser. Those therefore who order bridges, ships, or large boilers, should understand that they must give sufficient

Iron made to order and not kept ready made.

Must be made to exact sizes.

time for the iron to be rolled or else pay higher prices to cover the cost of buying ready-made iron. To this usage there are exceptions. Manufacturers of tanks, boilers, or structures made constantly to similar sizes and designs, can keep rolled iron in store without loss. Bar-iron of all sizes necessary for smiths' work may be safely stored, because in any case bars have to be cut, and no extra waste is involved. Rolled joists are also stored by iron merchants, because there are certain sizes that are in constant demand by architects and builders. But even in this case, joists have often to be cut to length, and the purchaser has to pay not only for the cutting, but for the pieces cut off to waste. When, therefore, any more than a small quantity of joists is required, it is usual to send a special order to the rolling-mill, so that the proper sizes and lengths can be made without waste and without extra cost for cutting.

Exceptions to rule.

Rolled joists kept in store.

See page 149.

Where the quantity required of any one kind of rolled iron is small, there is sometimes more time and trouble expended in obtaining it than for a much larger quantity, because it is not always convenient at a rolling-mill to put the rolls of suitable patterns into operation. For the same reason it is desirable in making a design, to avoid exceptional or peculiar shapes, or even numerous sizes of iron. All the usual sizes of round, square, or flat iron can be easily procured, but engineers who are furnished with the pattern-books of iron merchants or makers are too apt to consider that all the sizes or shapes in the book are equally obtainable, and in quantities however small. But unless the pattern-book be quite new, probably some of the shapes shown are obsolete or the rolls worn out. In other cases, the rolls for the exact pattern specified may exist at only one rolling-mill, and the purchaser may have no option but to agree to the price and the period of execution demanded. An engineer in an iron-making country, can, as occasion arises, modify his design, or allow some latitude in regard to exact shape and size, so as to meet these difficulties; and an engineer or purchaser in an importing country should also allow some latitude in regard to possibly necessary modifications. Sometimes an engineer, in his endeavour to make his design as perfect or symmetrical as possible, will adopt sections of iron varying by fine gradations in different parts of a structure, or will have shapes exactly appropriate to the purpose in view. Moreover, to add to the difficulty, the quantity required of each kind may be very small. In such a case, unless some reasonable departure from the exact detail be permitted, much additional cost and very greatly

Small quantities expensive.

Exceptional or peculiar shapes.

Limits competition.

Latitude necessary in choice of size.

Great variety increases cost.

If in small quantities.

extended time in execution will be incurred. If, however, the quantity required of any sort of rolled iron be large, any existing section may be chosen, as makers will be glad to put in operation the necessary rolls, and even to provide new rolls which can be made or adapted at a cost of from £20 to £100. In any case it is economical to adopt usual sizes of iron, and to avoid small fractional dimensions; plates within the limit of size described on page 143 so as to avoid extras; L or T bars of even figures, such dimensions as 3 × 3, 3 × 4, 3½ + 3½, being preferable to irregular or unequal sizes, such as 4 × 3¾, and 3 × 2⅞. On the other hand, when the exigencies of design demand it, it is well to take advantage of the patterns that exist, and the preceding remarks are only directed towards a prevention of unnecessary expenditure where small quantities are required, and no exact adherence to precise dimensions is really necessary.

Cost of new or altered rolls.

Irregular sizes be avoided.

The different classes of iron enumerated on page 135 may be described as follows.

Rails.

Rails, as forming a larger tonnage than any other kind of rolled iron, might, up to the year 1875, have been placed first in order of importance. In South Wales and the Cleveland district, nine-tenths or more of all the iron rails made in Great Britain have been rolled. It is needless to make any comparison of quality between these two districts, for the standard demanded by engineers has to be satisfied by each alike; and although the nature of the pig-iron and coal and some of the details of manufacture differ, the finished rail can be made in either locality as required. The manufacture of rails is a staple industry in Belgium, France, and Germany, and a considerable proportion in these countries is made from English pig-iron, but everywhere the introduction of steel rails has reduced the importance of this branch of the iron trade. Rails are fully described in another chapter.

Districts where made.

See RAILWAY EQUIPMENT, *Chap. XXI.*

Plates.

Plates are generally classified as for boilers, tanks, bridges, and ships, and their quality may be broadly placed in the same order. First in quality come the celebrated Yorkshire plates made at Lowmoor, Bowling, Farnley, and other works in the locality, and these stand apart from all other kinds. The high quality of these plates is obtained partly by the use of special material (cold-blast pig-iron for instance), but mainly by the elaboration and care in the manufacture. The iron is so carefully selected and thoroughly worked that all impurities are eliminated, and the plates when rolled are practically homogeneous, showing no signs of imperfect lamination. These plates are used for the fire-boxes of boilers, where the intense heat

Lowmoor and other high quality Yorkshire iron.

How made.

For what purposes.

would soon destroy inferior iron, for the entire substance of small boilers bent to sharp curves or subject to high pressure, and generally for places where iron has to be flanged, bent, pressed, or twisted in a manner which only the best iron can safely withstand. The tensile strength of these special irons ranges from 24 to 28 tons per square inch. There are many purposes for which rolled iron is needed, in which a high price for the material is of little importance compared with the ultimate cost of the manufactured article and the object in view. Amongst the varied engineering manufactures, the demand for these special irons is constant, and their high quality and the reputation of the makers have been maintained for many years. But, while for certain situations such iron is suitable, it is not expedient to use it generally for structural purposes, or for any situation where the high price is out of proportion to the advantage gained. Thus, for a bridge, it is evidently not economy to pay a double price for iron, which for the purpose in view, possesses qualities—tensile strength and elasticity—only 15 or 20 per cent. above the iron generally used. The price of these high-quality plates is generally double, or more than double, that of ordinary boiler plates. For certain purposes, such as for the wrought-iron domes of locomotives, for superior tin-plates, and for conversion into crucible steel, iron made with charcoal fuel is preferred to the special brands just described. The freedom from sulphur which the use of charcoal ensures, and the method of manufacture, ensures a peculiar softness and homogeneity otherwise unattainable. There are very few ironworks in England where such iron is made, and Sweden is the chief seat of manufacture, the abundance of timber and iron ore and the absence of coal having led naturally to the establishment of such a trade. Charcoal has become much scarcer than formerly, and large quantities of coal are imported into Sweden from England, and some of the so-called charcoal-iron is wholly or partially made with coal fuel.

Will endure severe strains. **High price, where justified.** **Where inexpedient.** **Price of Yorkshire iron.** **Charcoal iron.** **Swedish iron.** **Coal substituted for charcoal.**

Boiler plates. After the high-quality Yorkshire and charcoal plates, boiler-plates come first among ordinary irons, and while equal to a breaking strain of about 22 tons, approach nearer to the special irons described above than do plates rolled for other purposes. **Qualities needed.** According to the care bestowed upon them in manufacture they will withstand the constantly fluctuating strains caused by alterations of temperature, and may be bent to the curve of a cylindrical boiler and punched without damage. **Bridge plates.** The plates used in bridges, girders, and similar structures should be of a quality good enough to endure without damage the

punching, shearing, and other treatment necessary in manufacture, and to withstand without rupture a sufficient strain. The tensile strength of bridge plates usual in England is from 18 to 21 tons per square inch, and a ductility which gives from 8 to 10 per cent. reduction of area at the place of fracture. Such plates cost £1 per ton less than boiler plates. Toughness and elasticity are of more importance than a high breaking strain, and especially in the case of railway bridges which are subject to heavy percussions and vibrations. Tank-plates may be classed in regard to quality with bridge plates, any superiority they have being incidental to their lesser thickness and the greater working necessary in their production. Ship plates are, as a rule, inferior in quality to the bridge plates described above, and cost from 10s. to £1 per ton less. There is no good reason for this, and where no stipulation is made in regard to quality, and where mere cheapness of price is allowed to prevail by open competition among manufacturers, a ship and a bridge would probably alike be made of similar inferior iron. But the stipulations as to quality usual amongst the principal bridge engineers are higher than those by which a ship can (1880) obtain admittance to the usual desired classification at Lloyd's registry. As ships are exposed to strains which peculiarly require good iron to withstand them, one of the most useful alterations in the laws concerning ships would be an enforcement of a higher quality of iron, such as is even now demanded by the owners of first-class vessels who are not content merely to satisfy the demands of official inspectors. The use of steel for shipbuilding is raising the standard of quality.

Tensile strength.

See page 138.

Tank plates.

Ship plates.

Inferior quality.

Lloyd's rules satisfied.

The extras on plates may be approximately stated as follows, though some makers concede rather greater latitude. If not exceeding 4 cwt. (in some districts 5 or 6 cwt., and in the north of England even 9 cwt.) per plate, 30 square feet superficial area, 15 feet length, or 4 feet width, the ordinary current prices are charged. For every 5 feet additional length, an extra price of 20s. per ton; for every 6 inches in width beyond 4 feet, 10s. per ton; for any weight in excess of the standard up to 8 cwt., 20s. per ton; and a further extra of 20s. per ton for every 4 cwt. from 8 to 20 cwt; or 20s. per ton for every 10 ft. or part of 10 ft. beyond 30 superficial feet. Plates cut to irregular shapes are necessarily expensive, and if sizes or weights exceptionally large are wanted, special contracts must be made with the few makers who have machinery capable of producing them. Plates, after they are rolled, are sheared on all

Extras on plates.

Limits of length, width, and weight.

Irregular shapes.

Plates sheared to exact sizes.

sides to a size which will include the desired dimensions, but it is not usual without special stipulation for the plates to be cut at the rolling-mill exactly true to absolute dimensions. Such work is part of the process of manufacturing the plates into articles of utility. At many rolling-mills, plates up to 12 in. wide can be obtained rolled as bars, that is, with edges true and square enough to obviate the necessity for cutting or planing. Indeed, at some rolling-mills with powerful machinery, plates even 30 in. wide are rolled as bars, and sold at the ordinary price for plates. The use of such improved machinery is (1880) tending to alter the old-established rules for extras as just described.

Plates rolled as bars.

Limits of width.

Thin plates.

Plates less than ¼ in. thick cost from 5s. to 10s. per ton more than those ¼ in. thick and upwards, and these thinner plates are used principally for tanks, gasholders, and similar purposes. Below ⅛ in. thick the word plate becomes merged in that of *sheets*, and among English makers the thickness is no longer measured by fractions of inches, but by the Birmingham Wire Gauge (B. W. G.). Down to and inclusive of No. 20 B. W. G. (0·89 m.m.) sheets are known commercially as *singles*; from No. 20 down to and including 24, as *doubles*; and below this as *lattens*, the price rising in corresponding order. Besides this, if sheets are wider than 3 ft. or longer than 8 ft., or in any way have a larger area than 24 superficial feet, an extra price is charged, which mounts up from 10 to 40 shillings per ton very rapidly as the area is increased. Sheets after they are rolled are generally annealed to render them ductile, and are then in some cases re-rolled to give them a smooth surface.

Sheets.

B. W. G.

Extras on sheets, how regulated.

Annealed sheets.

Charcoal sheets.

See page 142.

The highest quality sheets are those made with charcoal fuel, which because of its freedom from sulphur, produces a very high quality of iron. Such sheets are made in small quantities in England, and cost about £8 per ton more than ordinary sheets. Sheet-iron of very high quality is made in Russia, charcoal not only being used as fuel for the ordinary purposes, but again after the sheets have been rolled; numerous sheets being piled together cold with charcoal between them, and hammered in a peculiar way. Sheets so made have a smooth glossy surface, unattainable by other means, and are not so susceptible to rust as ordinary sheets. They are used for the outer casings of locomotive boilers, as a casing to the wood lagging of steam cylinders, and for other purposes where a very smooth surface is required. In Russia they are even used—generally unpainted—as roof covering. They cost much more than ordinary sheets.

Russian sheets.

How made.

How used.

Corrugated sheets. Advantages. Sizes of flutes.

See ROOFS AND BUILDINGS.

See page 146.

Galvanizing. Value of, how determined. Inferior sheets. Charcoal sheets for galvanizing.

Though sheets are manufactured into innumerable articles of utility, they are of interest to engineers chiefly because of their use as galvanized corrugated roofing-sheets, of which very large quantities are made in England. The galvanizing protects the iron from corrosion, and the corrugations give great strength and stiffness to the sheets; the depth of flute determining the strength. In England the usual widths of the fluting are 3 in. and 5 in., and the depth ranges from one-fourth to one-fifth of the width. But as the strains during the process of corrugating test the quality of the iron in proportion to the depths of the flutes and the thickness of the iron, there is a tendency to make cheap sheets with shallow flutes, while engineers who want sheets for structural purposes often specify deep flutes. Galvanizing is an arbitrary and misleading name which has been applied to the process of coating iron with zinc or spelter. The value of the galvanised sheets depends upon the quality of the iron, the quality of the spelter, and the care, with which the process is performed. Although a certain minimum quality of iron is absolutely necessary to allow sheets to be rolled of the required thinness, yet, with this proviso, large quantities of inferior sheets are made, which, if carefully examined, will be found to have minute cracks or a blistered surface. Sheets of this kind will not hold the spelter properly; cannot endure the corrugation without risk of damage, or if safely corrugated, will not endure curving afterwards; and when exposed to the weather, soon become rusty. Charcoal sheets for galvanizing, although they can be obtained if really required, are not an ordinary article of commerce. The sheets that are sold at extra prices by manufacturers for galvanizing and other purposes, under the name of "charcoal sheets," are often made only with selected coal fuel and carefully worked.

Usual thickness of galvanized sheets. Thin sheets for the colonies. Price of galvanized sheets.

Galvanized corrugated sheets are made of various thicknesses, from No. 16 B. W. G. to 28 B. W. G., but for roofing and other ordinary purposes sheets thicker than 18 B. W. G. are seldom used. This is the gauge preferred by engineers in England for first-class work, but the sheets generally exported are of the thinner gauges, and in the English colonies especially, Nos. 24 to 28 are in constant demand, as the thinner sheets, though dearer per ton, cover more surface. The price of galvanized sheets, depending as it does on the current value of spelter as well as of iron, has no uniform relation to the prices current for iron, but assuming that spelter is selling at £20 per ton, then when boiler plates are selling at £10 per ton, galvanized corrugated sheets from 16 to 28 B. W. G. would sell from £16 to

Depends on price of spelter.

Packing for shipment.

£25 per ton, the thinner sheets being the dearest, not only because the thinner iron is the more expensive, but because in these sheets the proportion of spelter to the weight of iron is the greater. On the other hand, if deep flutes be required, the thick sheets will not so readily bend as thin sheets, and tougher and dearer iron becomes necessary. High-quality annealed sheets galvanized and cold rolled but not corrugated are made for working into articles of utility. Such sheets cost from £5 to £12 per ton more than ordinary galvanized sheets. When for use by the first purchaser in the country of manufacture, galvanized sheets are sometimes merely bundled together; but for shipment it is usual to pack them in cases, the cost of which adds from 15s. to £1 per ton to the price. But for protection from sea water, and in order to preserve the good appearance of the sheets for re-sale, the sheets are often enveloped in felt wrappers, sealed with pitch, and then packed in cases.

Skill in making galvanized sheets.

Has led to making bad sheets.

Inferior sheets soon wear out. *See* ROOFS.

Since the process of galvanizing was first introduced, manufacturers have acquired by experience increased aptitude and skill, which have enabled them to produce good sheets at a less cost than formerly. But unfortunately, increased knowledge has allowed the production of sheet-iron and galvanized sheets which, while of an inferior quality, look good enough to be saleable. There is no case where cheapness obtained by inferior quality is a falser economy than with galvanized iron, for the deterioration, when it commences, is in such sheets so rapid as to be out of all proportion to the first saving which may have been effected in price.

Bar iron.

Merchant-bars.

Well-known brands.

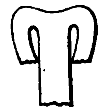
See TRADE-MARKS, *page 18.*

Fallacious brands.

Square, flat, round, and other forms of iron used by blacksmiths, and included in what are known as *merchant-bars* are made of various qualities, a proper choice depending of course mainly on the purpose for which the iron is required. A foreign purchaser who wishes to be safe can, as already stated, protect himself by stipulating for the brand or trade-mark of a well-known maker; but in distant countries a good deal of juggling takes place with regard to trade-marks. Indeed, there are large quantities of iron rolled in England specially for export with marks having some traditional importance to a foreign purchaser, but which are unknown among English users, and which may long ago have ceased to possess any real value. The true quality may, however, be ascertained by the following tests, which can only be borne by first-class iron, such as is sold by manufacturers of repute. Samples should be notched and bent back cold

to show the fibre of the iron. Both B and BB bars should endure 22 tons tensile strain per square inch with the grain of the iron. Square or round BB iron being forged hot may be punched with a punch one-third the diameter of the bar, at a distance of 1½ diameters from the end of the bar, and a second hole, at right angles to the first, at three diameters from the end of the bar. The holes may then be drifted out to 1½ times the diameter of the bar, and the sides of the holes being then split the ends must admit of being doubled back without fracture. Flat bars not exceeding ¾ in. thick may be bent with the grain to a radius of 2½ times their thickness without fracture. B bars may be punched as above, and drifted out to the diameter of the bar, and the sides of the holes should admit of being bent outward without fracture. Flat bars not exceeding ¾ in. thick may be bent with the grain to a radius of three times their thickness without fracture, and should endure punching and drifting also.

Forge test hot.



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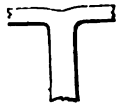

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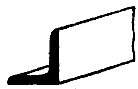
Ordinary sizes of bar-iron.

Round, square, and flat merchant-bars of all sizes from ½ in. to 3 in. wide are sold at ordinary rates, but below these dimensions the rates generally increase 5s. to 10s. per ton for every $\frac{1}{16}$ in. reduction. Above 3 in. prices also increase rapidly, so that bars 6 in. diameter cost from £3 to £5 per ton above the ordinary rates; the number of ironworks with machinery capable of rolling such large sizes is much less than for ordinary bars; and sometimes such bars are forged under the steam-hammer. Whatever be the thickness, if the size or length involve a greater weight than 6 cwt., extra rates are charged. Flat bars from 1 in. × ¼ in. to 6 in. × 1 in. are usually sold at current rates, and extra prices are charged for larger or smaller sizes, but wider bars, up to ¾ in. thick, made for use as plates, can be purchased at the price of plates. Variety in the lengths tends to cheapen the selling price of bars, especially where some long lengths are required, as bars which in the process of rolling fail to attain the extreme dimensions can be cut to the shorter lengths instead of being wasted.

Extras, how charged.

Limits of flat bars.

Bars of L or T form are rolled of all sizes, from 1 in. wide to 8 in. wide, but the greater number of sections between these limits are of dimensions between 2½ in. and 5 in. If not thinner than ¼ in., sections as narrow as 2 in. can be purchased at the current rate, but if thinner than ¼ in., then from 10s. to 20s. per ton extra is incurred. The ordinary current price is paid for all sections from 2 in. wide up to and including 8 united inches. That is to say, a section of 3 × 5 in. or 4 × 4 in. will, as not exceeding 8 in., be deemed ordinary, but for every inch beyond 8 in., an extra of about 10s. per ton is imposed;



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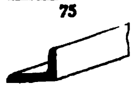

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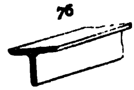

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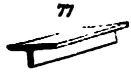

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Extras, how charged.

and moreover, if by reason of the thickness of the bars, a weight of about 4 cwt. is exceeded, an extra charge per ton of about 5s. is made for every cwt. in excess. Above a certain limit of length (which ranges at different rolling-mills from 20 to 40 feet for L bars, and 20 to 30 ft. for T bars) about 5s. per ton is charged for every 5 ft. of extra length.

Limits of length.

The exigencies of transport generally render pieces longer than 30 feet undesirable, but where the total length does not exceed 40 ft. it may be cheaper to make the bars in one length, and to pay extra carriage rates, than to divide and joint the bars.

Limits of thickness.

As the sizes become larger, so also must the thicknesses be increased, as thin iron becomes cool too soon while passing through the rolls. Thus bars 5 in. wide should not be thinner than ½ in., 4 in. bars than ⅜ in., 3in. bars than $\frac{5}{16}$ in., and so on. These limits may, however, be slightly overstepped by care in rolling, for which extra prices are charged.

Quality of L and T bars compared.

As stated on page 139, the iron in L bars is generally better, and of more uniform quality than that in T bars, as the grooves in the L bar rolling-mill are arranged so that the pressure upon each side is more equally applied than is the case with T bars. On the other hand, a T section is more symmetrical than an L section, and affords more convenient opportunities in a structure for joints and connections.

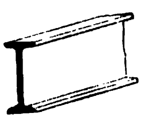
See ROOFS.

L bars are cheaper than T bars, partly because the process of manufacture is slightly easier, but mainly because the quantity manufactured is very much greater, rendering special arrangements feasible, and increasing the competition of makers. It is in these forms of bars that steel is most likely to supersede iron.

Straightening and cutting bar-iron.

Bars of all kinds as sold from the rolling-mill are only approximately straightened and are not cut to exact lengths, these being operations belonging to the boiler-makers, bridge-builders, or others who make them into articles of utility.

'oist iron.



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The use of I iron has very much increased during the twenty years ending 1880, but at no time since its introduction has such iron been so extensively used in England as on the Continent; and the quantity made in France and Belgium as compared with England is very much larger than is the case with any other kind of rolled iron. Although rolled iron joists can be made of a good quality, as they are at most of the English mills and at some of the Continental mills, a large proportion of the foreign iron is of inferior quality, and some of it is very bad. The method of rolling, while it works and compresses the web, puts little direct pressure on the flanges, and if a bar were

dissected and the web and flanges tested separately, the latter would be found inferior. Such iron betrays its quality if it be bent, welded, or smithed in any way; and unless a good quality can be ensured, such a treatment of it should be avoided. It is usefully and well applied for floor-joists or other girders of small span, for cross-girders in narrow bridges, or as longitudinal rail-bearers in a bridge. It is also used—especially on the Continent—for the rafters of trussed roofs, where in England T iron or a riveted girder would be preferred. In price, joist-iron varies according to the section and quality.

Best uses for joists.

Small and narrow sections, such as a depth of from 4 in. to 7 in., and a width of from 1 in. to 3 in. are the cheapest, the price rising slightly up to sizes 9 in. deep and 4 in. wide. Beyond these sizes the price increases, so that joists 12 in. deep and 6 in. wide would be from £1 to £2 per ton dearer; while if wider flanges be required, the price would be still higher, and the quality of the flanges probably inferior. Joists more than 12 in. deep can seldom be used with advantage, and above these dimensions riveted girders are in England generally preferred, though on the Continent, sizes up to 20 in. deep are constantly used; while as a *tour de force* they have been rolled as deep as 1 métre (39⅜in.) In this case, by an ingenious machine with numerous rolls, the flanges are compressed as well as the web, and if such a method of manufacture could be applied to all joists, their quality and usefulness would be greatly increased. The smaller sections can generally be purchased up to 25 ft. in length, without extra charge, and the larger sections up to 20 ft. If these dimensions be exceeded, an extra price is incurred, somewhat in the same ratio as for T iron. But with joists, as with other rolled iron, exceptions are made to the rule when the transaction is in other respects favourable to the manufacturer; and sometimes in such cases, lengths varying from 20 to 40 ft. are supplied without extra charge.

Price varies according to size.

Small and narrow sections cheapest.

Limits of size.

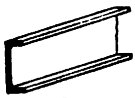
Limits of length.

See page 148.

Rolled joists are kept in store by iron merchants in most large towns, so that builders can purchase them as wanted, but, as already stated, in such cases the expense of cutting to length has often to be incurred, which, together with the value of the piece cut off, brings the retail price generally £1 to £3 above the current price at which such joists can be bought at the rolling-mills. The ordinary practice is to cut the ends of the joists hot as they leave the rolls, and a length which is within 1 in. of the specified dimensions is considered sufficiently accurate. If cut at the rolling-mill to exact lengths cold, an additional cost of from 3s. to 10s. per ton is incurred.

Ready-made joists.

Cutting to length.



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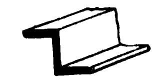

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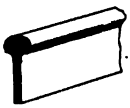

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Channel ⊔ iron bears somewhat the same relation to I iron as a T does to an L section, and although extremely useful in many cases, their one-sided shape renders them less easy to bend and less convenient for connections than the double T. The smaller and narrower sections are the cheapest, and in this respect, and in the rules by which extras are charged, they may be classed with I joists, as also in regard to the fact that they are largely made in Belgium and France. The prices are generally about £1 per ton higher than the prices of joists.

Z iron and bulb iron are used principally by shipbuilders, and cost about the same as T bars. Hoop iron is made of many qualities, the cheapest being used by builders for bonding brickwork together; a better quality is made for hooping casks; and the best for enclosing bales packed tightly by hydraulic pressure. Hoop iron of ordinary sizes costs about the same price per ton as that current for boiler plates. If the thickness be less than 19 B. W. G. for 1 in. wide, or 17 for 2 in. wide, extra prices are charged. Steel hoops are coming into use instead of iron hoops where strength is of importance.

Steel.

How it differs from iron.

Steel has three main qualities which distinguish it from iron. (1) Its superior strength; (2) its durability or resistance to wear or abrasion; and (3) its capacity for being tempered, although for this latter purpose the mild steel used in structures is not suitable. It is its strength which renders steel suitable for structures (ships, bridges, roofs, &c.); its strength and resistance to wear, which adapt it for boilers and machinery; its durability against abrasion, which makes it so valuable for rails, railway-points, wheel-tires, toothed wheels; and its highest quality—the capacity for being tempered—which distinguishes it from all other materials as alone suitable for cutting-tools and springs. The employment of steel for these very different purposes may be further elucidated as follows.

Advantages afforded by steel.

See RAILS.

Comparison of steel *v.* iron altered by Bessemer inventions.

In estimating the qualities and cost of steel or the expediency of using it instead of iron, the revolution caused in steel-making and the steel trade, by the Bessemer inventions, must be carefully borne in mind. So widely different are the old and new processes by which steel is made, and so subtle and minute the causes which produce wide differences of quality, that even the name itself *Steel* has become a subject-matter for dispute, and one in which no authoritative standard or definition has been agreed upon. The old plan of making crucible steel by an elaborate process from high-quality Swedish iron is still

Crucible steel, when used.

carried on, principally at Sheffield; and the finer articles of utility, such as turning-tools, punches, chisels, screw-taps, dies and cutlery, are made from this kind of steel as formerly. But the Bessemer inventions, by which steel is made directly from pig-iron, and the after inventions of Siemens and others, by which steel is either produced from scrap steel, pig-iron, or even from the richer iron ores without the intervening pig-iron process at all, or from a mixture of each, are the causes which have rendered steel cheap enough to be available to the engineer for purposes never practicable before. The advantages afforded by the use of steel for rails are described in another chapter; but it may said here that it was not only the high price of crucible steel that prevented its application on a large scale for rails, bridges, and constructional purposes, but also because steel-makers had formerly too little knowledge of engineering, and of the various strains to which their products would be subjected, and too little experience of their action under varied circumstances, to manufacture in each case the most suitable quality of steel for the work required. High tensile strains were aimed at even for purposes where only moderate strength was needed, and the strong steel so produced did not afford the toughness which was needed, and the failures that resulted from such misapprehension did much to shake the faith of engineers in steel as a new material for structures.

Bessemer process.

Steel from pig-iron.

Direct conversion from iron ore.

Steel rails. *See Chap. XXI.* RAILWAY EQUIPMENT, *also page 141.*

Mistakes in early use of steel.

See page 152.

The use in structures of Bessemer steel, which is here meant to include the steel made directly from iron by any of the successful modern processes, was for some time after its invention in a transition state, unsatisfactory alike to engineers and to steel-makers; and even since the manufacture of steel has been rendered more certain, there are various secondary reasons which limit its use. Many of these have been already alluded to under the head of bridges. At first sight, there appear so many advantages in using steel, that it may seem astonishing that boilers, ships, or bridges are made of anything else. But on closer investigation, the question is found to be a complex one. The tensile breaking strength of steel for these purposes may be roughly stated as from 40 to 100 per cent. more than wrought-iron, and about the year 1877, the prices of iron and steel, having continued to approach since 1870, were in about the same ratio. But as the cost of the iron or steel is only one out of many expenses of manufacture, even if the weight of a boiler, bridge, or ship could be reduced one third, the cost would still be greater, even if the same strength were maintained. The cost of steel bars and plates has since 1877 approached

Causes which have retarded the adoption of steel.

See BRIDGES, *Part I.*

Strength of steel compared with iron.

Comparative cost.

by steady gradations nearer to that of iron, and as the process of making steel is simpler than that of making wrought-iron, it may be expected to maintain a price not very different if suitable raw material be obtainable. But while experiments have shown that steel may be one half and more stronger than iron, engineers, for reasons stated below, have not yet placed that confidence in it which its strength and the certainty with which it can now be produced would warrant. Steel is not so easily welded as iron, and, even in more ordinary smithing processes, unequal heating may alter its temper. It is due to the risks of welding that steel chain made of the shape usual in iron is unknown to to commerce. Moreover, steel is more liable than iron to damage from such operations as the punching of rivet-holes, which tend to weaken the surrounding parts. And the homogeneity of steel, which is an advantage in many respects, allows a crack or flaw, when once commenced, to spread in a way that is impossible in fibrous wrought-iron, where a crack has to take a fresh departure at each fibre that it meets. The annealing of steel, after it has been punched or subjected to cold hammering, generally restores it to its original temper, and many of the other difficulties and the supposed objections to its use have disappeared as workmen have become as used to it as they had been to iron; and the success hitherto (1880) leaves little doubt of its ultimate adoption for general purposes, where only simple and moderate smithing and welding is required, and especially in structures so designed that simple rolled bars or plates may be used without smithing. But as already stated, most of the accidents with steel arose from the desire to utilise too fully the strength of the new material, and when steel equal to a breaking strain of 40 tons per inch was preferred. And as the capacity of elongation and the toughness to resist bending become less as the hardness and tensile strength increase, such steel was much more liable to fracture from percussion or from other treatment to which structures during manufacture or use are liable than mild steel. The real value of either wrought-iron or steel depends not only on the ultimate breaking strength, but on the limit of elasticity, and steel has a much higher proportionate limit than iron. Thus, while iron of 20 tons breaking strain will have 10 tons as a limit of elasticity, and Lowmoor iron of 28 tons breaking strain 14 tons; steel of 36 tons will have a limit as high as 26 tons. In the case of the steel plates used for shipbuilding in the Royal Navy, a strip is cut from every plate and tested, and it is (1880) specified that the breaking strain shall not exceed 30 tons per square inch, but that there shall be

Difficulties.

Welding of steel.

Injury from punching.

Cracks spread more than in iron.

Annealing of steel.

Simple shapes best to avoid smithing.

Strongest steel not best for structures.

Superior elastic limit of steel.

See page 142.

Quality of steel plates.

Navy plates.

such ductility that a piece of 8 in. long shall stretch 20 per cent. before fracture. Up to 1875 such a condition would have been prohibitory. By the use of such steel the weight of a vessel may be greatly reduced, and the plates will safely endure the collision or indentation which would destroy iron plates. There remains still the great advantage of a reduction in weight which the use of steel allows; and it is in cases where this is of the first importance, as in long-span bridges (already described) and in vessels for carrying heavy as distinguished from bulky cargoes, that steel is most advantageously employed.

Reduction in weight allowed.

As in bridges and ships.

Boilers of steel have, besides the advantage of lightness, that of allowing, through their thinness of shell, a more rapid transmission of heat to the water, and having a smoother surface there is less liability to scale; steel is also a better transmitter than iron. And as even the best Yorkshire plates which are used for the exposed parts of boilers are occasionally found defective, the more certain steel is becoming preferred, and is cheaper.

Steel boilers.

See LOCOMOTIVES, *Chap. XXII.*

Steel when manufactured into articles of utility cannot be easily distinguished from iron, and the want of some ready mode of satisfying themselves that proper steel has been employed, is one of the causes which disincline engineers from allowing its use. Some authoritative brand or hall-mark seems needed to verify the origin of each separate piece, for the testing a portion of every piece is troublesome and expensive. This verification of quality is more important than in the case of iron, where the inferiority of any particular piece would probably be, at most, 10 per cent.; while, if iron or bad steel be substituted for the prescribed steel, the difference might be 50 per cent. As in the Bessemer process, from 5 to 10 tons of steel are "blown" or "converted" at the same time in one vessel, it would appear that the chemical and mechanical tests which are usually made should suffice for all the steel so converted at one time, while in the crucible steel, where each vessel contains only from 60 to 120 lbs., there is not the same certainty that the contents of numerous crucibles will be alike.

Steel not easily distinguished from iron.

This limits the use of steel.

Test of sample may serve as test for bulk.

While the demand for steel remains comparatively small and uncertain, its price cannot be stated with the same precision as the prices of iron. Steel plates for boilers cost (1880) nearly double the price of iron plates; while steel plates for bridges or ships, can be purchased at about £4 per ton more than iron plates for similar purposes. Steel bars of L or T form can be purchased at from £3 to £5 more than for iron, but the number of section patterns

Prices of steel.

Ship and bridge plates.

is much smaller than those available in iron, though as the demand for steel increases, it may be expected that the forms and sizes of it will become as numerous as in iron. And it is in L, T and other forms used in structures, rather than in the round and square forms used for smith's work, that steel is likely in the future to supersede iron. Steel sheets useful for many purposes, but not often to engineers, cost from £5 to £10 more than iron sheets of good quality used for galvanizing. In the case of steel, as of iron, competition is not limited to England, and many of the Continental manufacturers are enterprising enough to offer great inducements to English purchasers. There is no doubt that in England and on the Continent, if the use of steel became extended, and a demand arose for it, the expenses of manufacture would, as in the case of rails, be lessened as the quantities became greater, and the prices would approximate more nearly to those of iron. It is (1880) too soon to state the extras which will be reckoned on the current prices of steel for excess in size or weight beyond the ordinary sizes, but both in regard to bars and plates much larger sizes are allowed without extra charge than are customary in iron.

Steel bars. **Steel sheets.** **Prices likely to be reduced as use of steel extends.**

Cast steel improved by hammering and rolling.

Steel owes much of its homogeneity and close grain to the treatment it receives by hammering and rolling after it has been cast into an ingot. It is for want of such after treatment that steel castings do not offer the tenacity and ductility of wrought steel. Molten steel, after being cast, chills more quickly than iron; the process of casting is not so easy; there is more risk of unsoundness; and for these reasons, steel cast into irregular shapes, unless it be afterwards compressed, hammered, or rolled, always offers a strength inferior to that of simple shaped rolled steel bars. Whitworth's process of compressing steel castings while in a semi-molten condition, was introduced to meet these objections, and so far as it has been applied—chiefly (up to 1880) for military purposes, such as guns and torpedo-cases—it has proved very successful. The application of steel to general purposes, such as the parts of large steam-engines and machinery, will much depend on whether it can be produced of good quality in large masses without forging. It is largely owing to the difficulty of obtaining sound steel castings of irregular shape, that malleable cast-iron is so extensively used. Made from high-quality (generally hæmatite) pig-iron, sound castings are more easily made than in steel, and such iron castings are then, by a peculiar process of annealing, partly decarbonized and rendered so tough as to withstand bending or percussion without fracture.

Steel castings. **Compressed steel.** **Large castings.** **Malleable cast-iron.**

Advantages of steel castings.

But simple steel castings, when sound, offer considerable advantages over iron castings, where great strength and reduction in weight is required; especially where a greater resistance to wear and abrasion is of importance. They even take the place of wrought-iron for irregular shapes, where the cost of forging or smithing is great; but in such cases, care must be exercised in their introduction, as though in such steel castings a higher tensile strength is obtained than in the best Yorkshire iron, there is little elasticity, so that scant warning would be given of their ultimate fracture. Steel castings compare most favourably with iron castings under tensile strains, as they have a tenacity three times or more than that of cast-iron, or over 30 tons per square inch. The value of resistance of steel to torsion is, as compared to wrought-iron, as 2 to 1, so that wherever torsional strains have to be endured, as in screw-shafts of steam-ships, steel is of high value. Owing to the expense of forging and rolling long, heavy, round iron, steel for screw-shafts or for screw-piles is often cheaper than the same forms in iron. And as steel has also a much greater resistance to abrasion than iron, toothed wheels are for this reason often made of steel.

Tensile strength.

Steel in torsion.

Steel shafting and screw-piles.

Steel instead of high-quality iron.

Steel is gradually being introduced for various purposes where formerly only the best brands of Yorkshire iron were used; and merchant-bars of steel can be purchased at much lower prices than this quality of iron. It is not so much the ultimate purpose, as the treatment to which the steel will be subjected while being converted into articles of utility, that determines the choice.

Prices of crucible steel for tools.

Such articles as turning-tools, screwing-taps, chisels, files, saws, are usually made from crucible cast-steel, which ranges in price from £30 to £60 per ton; but some special kinds of tool steel cost more than £100 per ton. The higher grades of crucible steel are melted from the best brands of Swedish iron, which vary in price from £12 to £30 per ton; so that the quality of steel may be infinitely varied, according to the mixture of high or low-priced iron.

Various shapes of tool steel.

Tool cast-steel is made in bars of various shapes and sizes, such as square for turning, slotting and planing tools; round, for taps, rimers, drills, milling-tools, dies; flat, for turning and slotting-tools and shear-blades; round-edge, for chisels and riveting-snaps; octagon, for chisels and snaps. Various tempers are required for these different purposes, and the maker should always be informed of the particular purpose for which the steel is to be used. For want of such knowledge, steel, though of good quality, is often not adapted

Various tempers.

for the purpose in view. It is false economy to use anything but crucible cast-steel of good quality for tools working upon metal, as the higher cost of good steel is more than repaid by its greater durability, and the great saving of time in resharpening. But prices more than proportioned to their value are charged for some of the best known brands of steel.

Good steel saves expense.

See MACHINE-TOOLS, *Chap. XXIII.*

Shear-steel for welding.

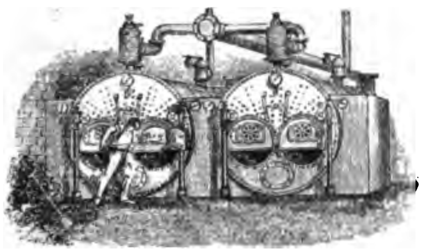
Shear-steel is generally used for welding purposes, and varies in price from £30 to £60 per ton, the higher qualities being used for machine cutting-tools, composed of steel and iron welded together. Railway springs are made from various qualities of spring steel, which are known in the trade as Swedish spring steel, *i.e.*, rolled from Swedish bar-iron cemented, and not from Swedish-Bessemer-steel; British crucible cast-steel; Siemens-Martin steel; and Bessemer steel. The bulk of the laminated springs are made from Swedish or Bessemer-steel. The Swedish steel springs first named in the above category cost from £6 to £10 per ton more than the latter.

Spring steel.

[*See also* CONTRACT AND PURCHASE: PURCHASE FOR EXPORT: IRON ROOFS AND BUILDINGS: *and in* PART I., BRIDGES.]

CHAPTER XIX.

THE PURCHASE OF STEAM-ENGINES. PORTABLE ENGINES. GAS-ENGINES. HOT-AIR ENGINES. WATER-ENGINES.



THERE are three natural sources from which mechanical power may be obtained in substitution for animal force—the Wind, the gravity-force of Water, and the potential heat-force of Fuel. Fuel is utilised in several ways, but amongst them the steam-engine has hitherto proved to be the most convenient and useful in the majority of cases, the exceptions being generally those where only a small power is desired. As, however, the effective force afforded by the combustion of fuel, even in the best kind of steam-engine, is still far below the theoretical heat-force of the fuel, and as, moreover, there are certain inconveniences which attend the use of the steam-engine, constant attempts are made to discover other methods of transmuting heat into mechanical force, either by improvements in the engine itself, or by means which avoid the use of steam altogether. Among the latter, gas-engines, hot-air engines, and even electric-engines find advocates; while outside any category of heat-motors, water-engines are available, not only as original motors where there are natural sources of water, but also for giving effect to the gravity-force of water which has been pumped up by a steam-engine or other prime mover at a distance. It is not intended here to describe or suggest any new method, but only to draw attention to the circumstances by which the value of steam-engines and the substitutes above mentioned is determined.

Natural sources of power.

Wind, water, fuel.

Fuel force utilised in steam-engines.

Other kinds of heat motors. *See page 193.*

Water-engines. *See page 194; also* TRANSMISSION OF POWER, *page 78.*

The primary measure of value in a steam-engine is its power; but

Steam-engines valued by their power.

this, as it is derived from the fuel consumed in the furnace of the boiler, depends in the first place on the size or capacity of the boiler and furnace. The gross heat-force being thus arrived at, the net effective value depends on the waste or loss between the heat-force units contained in the fuel and the mechanical-force units given out; this waste or loss depending on the design and construction of the machine. Such a simple measure, though that generally prescribed by theory, is not however sufficient; for it is the suitability of an engine to the special wants of a purchaser which determines its value in any particular case; and the power which one engine as compared with another will give, is only one out of many points which have to be considered.

Other conditions of value.

Variety in kind of engine perplexing.

The diversity of purposes to which the steam-engine is applied has been met by a corresponding variety in the kinds of engines; and this variety, though advantageous in the wide choice it affords, is often a source of perplexity to the purchaser. Inventors and manufacturers draw attention to the points of excellence in their machine, to the conveniences it affords, and the difficulties it overcomes; and till another set of conveniences and difficulties is considered, it might be thought that one particular engine must be the best for all cases. Precedent should not be followed, nor success already achieved be taken as a guide, unless the conditions of use are sufficiently alike. Engines and boilers are often sold separately; but as the boiler is one of the most important parts of a steam-engine, no proper choice can be made of one without due consideration of the other. A purchaser of a steam-engine has generally to consider, besides the primary question of the power required, some of the following points, which conflict with each other in a variety of ways; and on the circumstances of locality and purpose their order of importance depends.

Precedent should not always be followed.

Points to be considered.

Enumerated.

1. The *space* to be occupied by the engine and boiler; for if there be limitations in this respect, the design of the engine may be modified accordingly. Thus, a very high pressure of steam may be adopted, so as to reduce the size of the cylinder and of other parts; and a boiler may be chosen of a kind which will allow rapid generation of steam, though it may not conduce to economy in fuel. Or, expressly to meet such cases, engines may be made without connecting-rods and other usual adjuncts which occupy space. If floor space be limited, some kind of vertical engine and boiler may have to be adopted, which may be less solid and durable and more expensive than a horizontal engine.

Exigencies of space.

2. The *weight* may be a point of consequence, if the engine and boiler have to stand upon an upper floor, or on a weak foundation. If weight for transport is an important consideration, not only the total weight, but that of the separate pieces must be considered, and the larger pieces, such as boiler, bed-plate, and fly-wheel, may be made to subdivide for carriage. **Weight of engine.**

3. If frequent *carriage* from place to place be probable, a portable engine may be best, but if only occasional moving has to be anticipated, a fixed engine with parts conveniently divisible may be preferred. **Portability.** *See page 183.*

4. Facility for *fixing* and setting to work is sometimes an important point, and it may be expedient to make the machine so complete and self-contained as to require little preparatory labour in buildings and foundations, and no preliminary adjustment of the mechanism as a condition of proper working. **Facility in setting to work.** *See pages 182 and 188.*

5. The necessity for *simplicity* of working may render it inexpedient to have certain special valves and other parts, which, if skilled workmen were in attendance, might allow economy of fuel and other advantages. **Simplicity of parts.**

6. A minimum *time* for starting may render necessary a peculiar kind of boiler and other arrangements; the steam-engines for cranes, winches, and fire-engines being examples. **Quickness in starting.** *See page 219.*

7. Equable *working* and facility of adjustment may be of great consequence, and may render necessary or convenient expensive control mechanism. The machinery for spinning fibres and weaving fabrics, and the electric-light machines, need such equable-working engines; and special governors, or automatic control-valves of a very sensitive kind, may be necessary. **Equable working.**

8. Economy in *fuel* and suitability for particular kinds of fuel are conditions which often modify the design; but the extent to which the engineer can meet these conditions is often limited by other of the points mentioned. **Economy in fuel.** *See page 162.*

9. Economy in first *cost* often overrides all the other considerations, for, though it might be cheaper eventually to have only what is best and most suitable, even a rudely-constructed engine, or one consuming much fuel (if the only one which can be afforded) may still prove of great advantage when compared with other sources of power available as an alternative. Of course, in measuring the cost, or in comparing one kind of engine with another, the expenses of foundations and buildings, and other accessories need as much consideration as the machine itself. **Cheapness of price.** **Cost of accessories must be included.** *See page 180.*

Horse-power. In all technical questions concerning steam-engines, and in their commercial valuation, the "*Horse-power*" is by common usage adopted as the unit of measurement; but as the term is qualified by the prefix "Nominal," "Indicated," "Effective," "Real," the relation which these phrases bear to each other needs explanation. **Different terms elucidated.** Watt, in introducing his new steam-engines one hundred years ago, required a convenient and easily understood measure of power, by which the value of his engines could be stated; **Watt's rule.** and having by experiment ascertained that a very strong horse could lift 33,000 lbs. one foot high in one minute, he adopted this as his standard, for although 25,000 lbs. would more correctly represent the usual power of a horse, Watt preferred the higher figure, as demonstrating with greater effect the value of the machine he had invented. The lifting one pound one foot high has, **Foot-pounds.** under the name foot-pound, been adopted as an unit of measurement for the power not only of steam-engines, but of all kinds of mechanical forces. Watt made the parts of his engines of such dimensions and capacity as would, with the steam-pressure at his command, produce the required power; and the sizes of the principal parts—notably the diameter of the steam cylinder—thus determined, became established, though informally and with certain modifications, as standards among engine-makers. **Standard rule adopted.** Watt's standard has been adopted in most foreign countries. In France, where metrical measures are in force, 75 kilogrammètres (kilos lifted one mètre) per second are taken as one-horse power, and this equals 0·986 of the English horse-power. **Metrical equivalent.** In Germany **Foreign H. P.** the horse-power slightly exceeds the English standard; in Russia it is exactly the same as in England. Watt based his calculation of horse-power upon an assumed steam pressure (in addition to the vacuum-force he obtained) of 7 lbs. per square inch, and a piston speed of 160 feet per minute; **Steam pressure assumed by Watt.** an increased piston speed being adopted as the stroke was made longer than 2 ft., so that with a stroke of 8 ft. the speed was calculated at about 260 ft. per minute. The same rule would apply for the earlier non-condensing, or as they were called, high-pressure engines, but with a direct steam pressure of 21 lbs. **No longer used.** But with the use of higher pressure steam, of greater velocities, and of numerous improved methods, engines made now of the same dimensions as formerly, give out much greater power; **Power increased by high pressure.** and hence the difference—2 to 1, 3 to 1, or even 6 to 1, as the case may be—between the nominal and real power of a steam-engine made now of the old dimensions. Watt's dimensions have not been strictly adhered to, and though no absolute rules have been established, the competition of makers has led to conven-

tional standards of size in different districts. Among the various modifications of Watt's rule, that which allows a non-condensing engine, about 10 circular inches of piston area for each nominal horse-power is one of the most simple and usual. Thus, a cylinder 8 in. diameter, having an area of 64 circular inches, will be provided for a 6-horse power engine, a 10-in. cylinder for a 10-horse power engine, and a 12-in. cylinder for a 14-horse power engine. It is evident that an arbitrary rule of this kind may be applied with widely different results, according to the length of stroke, pressure of steam, speed, and other circumstances. So long, however, as there is an understanding acted on by makers of engines and known to purchasers, of what dimensions are really implied by a certain specified nominal horse-power, the term, though arbitrary and conventional, cannot be called useless; and until engine-makers in different countries agree upon some better method of denominating their machines, the old term will be used; and if it be attempted instead, to state the real power, then as this depends upon the pressure and velocity—incidents which may, in an engine of given dimensions, be varied at will within very wide limits—such a statement, unless accompanied by the exact conditions upon which it is calculated, might not convey to the purchaser of a steam-engine so good an idea of the machine in question as would the nominal horse-power, which implies certain conventional or prescribed dimensions. For the same reason, there is no fixed proportion between nominal and real horse-power. Amongst engineers the nominal horse-power is seldom referred to, the real power, as determined by the dimensions, pressure, and speed, being alone considered.

Power according to piston area.

Affords variable results.

Nominal H. P. implies a certain real power.

Difficulties in stating real power.

Engineers ignore nominal H. P.

By means of an instrument called the "indicator," the pressure per inch upon the piston, with the variations of pressure at each portion of the stroke, are exactly measured and recorded; and the mean of such varying pressure, multiplied by the number of inches of piston surface, gives the total force exerted upon the piston. This total force, when again multiplied by the number of feet travelled by the piston per minute, produces the sum of foot-pounds of work done, which, divided by 33,000, expresses the "indicated horse-power" according to Watt's standard. But, from the gross power thus arrived at, must be deducted—if the net or effective or real power is to be ascertained—the power consumed in overcoming the friction of the engine itself; and in the majority of cases—in each according to the skill of the maker and other conditions—the proportion to be deducted is somewhere between one-fifth and one-tenth of the gross power, or an

The indicator.

Shows pressure and speed.

Indicated H. P.

Real or effective H. P.

Dynamic force. average of about 15 per cent. The effective or dynamic power can, if desired, be exactly measured in all engines of moderate size, either by a dynamometer, or by a friction brake, as has often been done in the competitive trials of engines.

Economy in work depends on fuel consumed. Subject to due consideration, in special cases, of the circumstances enumerated on page 181, economy in working is that which is most important, and economy depends mainly on the consumption of fuel; the exceptions being principally those where a steam-engine is **Exceptions.** wanted for merely temporary use, or where—as in a coal-pit or forest—fuel is so cheap and abundant as to need no consideration, or where, because of the smallness of the engine, the cost of fuel, even if excessive, bears but a small proportion to the total expense of working, or where the waste steam can be utilised for other purposes, as sometimes is the case in paper mills or sugar factories. The **Example of fuel consumption.** relation which the cost of fuel bears to the purchase-money of an engine, and the extent to which economy may be practised, may be illustrated by an example. Let it be assumed that an ordinary non-condensing engine of 20 nominal horse-power will cost, including boiler, about £500; and let it also be assumed, that such an engine will be worked at a pressure and speed which will give out 50 indi**In non-condensing engines.** cated horse-power. With coal of ordinary quality, the consumption will probably be some quantity between 5 and 10 lbs. per indicated horse-power per hour, the lower amount requiring a well-designed engine and good stoking, and the higher, though generally implying an unnecessary waste, being not greater than takes place in many engines. Assuming that the engine is working 60 hours per week, or 3,000 hours per annum, the yearly consumption of fuel will be from 335 to 670 **Saving effected by using steam expansively.** tons, which, at the value of £1 per ton, shows a difference, and therefore allows a margin for saving, of £335 per annum. If high-pressure steam be used expansively, and the feed-water heated with the exhaust-steam, the consumption may be reduced to lower limits, say from 4 to 7 lbs., according to the skill in stoking and other circumstances. But even the lower of the two rates involves a very **Further saving by condensing.** unnecessary consumption of fuel. An ordinary condensing engine, to produce the same indicated horse-power, would probably cost about *See page 171.* £600, and would consume only from 3 to 5 lbs. of coal per indicated horse-power per hour; and by the skilful use of compound engines, and well-arranged boilers, the consumption can be kept **Minimum consumption.** down to 2 lbs. It is even asserted by the inventors of special engines or boilers, or of apparatus connected with them, that 1½ lbs.

only is necessary; but although by the use of carefully-selected coal, and under very favourable circumstances, such a low rate may have been reached as an experiment, it can hardly be relied on as a standard in actual practice. As, however, even 1½ lbs. is far in excess of what in theory will generate steam equal to 1-horse power, it would be presumptuous to affirm that further economies are impossible in the future, and it is obvious that any saving that may be effected will have special value in countries where coal is dear.

See COAL, *page 119.*

Economy in fuel, how obtainable.

Economy in fuel depends upon the proper construction of both engine and boiler, and can only be maintained by skilful management, these essential conditions requiring that—

Waste of fuel in furnace avoided.

(*a*) The fuel shall all be consumed in the furnace without being wasted either in the form of combustible cinders, smoke, or vapours. To this end it is necessary that the boilers shall be of a proper kind, and properly set.

Escape of heat prevented.

(*b*) The heat generated in the furnace shall all be transferred to the water in the boiler, and shall not escape either into the stoke-hole or up the chimney, this requiring a large heating surface and efficient stoking.

Loss by radiation avoided.

(*c*) The heat in the boiler shall not be wasted by radiation from the boiler or from the pipes which conduct the steam to the engine; and to ensure this, the boiler, steam-pipes, and cylinder must be protected from loss by radiation by some non-conductor of heat.

Steam all to be used in engine.

(*d*) The steam which reaches the engine shall be utilized there to the utmost, and therefore none of the steam in the engine shall be allowed to escape till all or as much as possible of its direct and expansive force has been utilised.

Friction of engine kept low.

(*e*) The force necessary to overcome the friction of the engine itself, and which is lost from the effective power, shall be kept as low as possible; and therefore that the engine shall be as simple as possible, and so well fitted as to require the minimum of power to work it.

Boiler and engine considered separately.

While, however, economy thus depends both upon the boiler by which the steam is produced and upon the engine which uses it, the two are entirely distinct, and need separate consideration.

Boilers.

[redacted]

The earliest *Boilers*, though made of various forms—egg-ended, wagon-shaped, circular with domed tops—were without internal flues of any kind; the furnace below the boiler and the flues around it being constructed in brickwork. Although much skill was some-

Consuming much fuel.

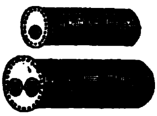
times shown in the arrangement of the flues, a large proportion of the fuel was wasted either in the form of unburnt coal and cinders or in the smoke and heated vapour allowed to escape up the chimney. The water could not be heated quickly, and boilers of large size were necessary to produce sufficient steam. Boilers of this kind are very seldom made now, and are mostly to be found at collieries and places where there is much cheap fuel, or where there is refuse fuel, a riddance from which is desired, or where the waste heat from coke

Wagon boiler.

ovens or furnaces can be utilised. The wagon-shaped boiler, which contains one tube or flue, was an advance on the previous kind; but the great advantages as regards strength which a circular shape allows,

Cornish and Lancashire boiler.

caused the wagon shape also to be superseded. The Cornish boiler and the Lancashire boiler were a marked improvement upon any of the previous kinds. They are of cylindrical form, generally of some diameter between 3 ft. 6 in. and 7 ft., and of some length between 8 ft. and 30 ft. They contain one or two internal tubes or flues, boilers not exceeding 5 ft. diameter generally having one, and those more than 5 ft. diameter two, of such tubes; those with one tube being known as Cornish, and those with two tubes as Lancashire boilers. The tubes are of some diameter generally approximating to one-half of the diameter of the boiler when there is one tube, and



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How arranged.

to one-third when there are two tubes. In each tube is placed a furnace, and the flames and heated vapours having passed along the tube are, in the majority of cases, then taken under and along the outside of the boiler in brick flues, and thence to the

Advantages.

chimney. The advantages afforded in the heating of the water by thus having the furnace and the hottest of the vapours in the interior of the boiler are obvious; and boilers of smaller size than those without internal flues will produce as much steam in a given time.

Multitubular boilers.

Multitubular boilers are either vertical or horizontal, and almost always cylindrical, except for marine engines, where they are sometimes of such shape (generally rectangular) as will best suit the exigencies of space in a steam-ship. But even in marine boilers the advantages of a circular form have led to its adoption to resist high-pressure steam. In multitubular boilers there is the same principle of internal flues as in a Cornish or Lancashire boiler, but instead of one or two tubes there are numerous tubes of small diameter, generally from 1½ in. to 3½ in. diameter, through which the vapours pass to the chimney. The heated surface which is presented

to the water, by thus piercing it with a multitude of fiery tubes, is in the aggregate very great, and steam can be produced rapidly; a great reduction in the size of the boiler is allowed; and it can be made complete or "self-contained" without the necessity for any brickwork flues or setting. If the adoption of this method of constructing boilers were not limited by certain opposing considerations, all other kinds would be soon abandoned. The question is an important one, on which there are constantly diverse opinions. The multitubular boiler was first designed for locomotives, as, in the small space there available, one or two internal tubes of large diameter were totally inadequate. The rapidity with which water can be heated and steam generated in a multitubular boiler, (so that from a boiler of limited size a large supply of steam can be kept up) at once ensured its adoption. In a locomotive, although economy in fuel is desirable as in other engines, the production of sufficient steam in a boiler whose size is necessarily limited, is the primary consideration, and the one which renders the multitubular system absolutely essential. But even the numerous tubes would be insufficient to produce steam quickly enough for the purposes of a locomotive, were it not for the happy addition of the steam-blast. The exhaust-steam from the engine cylinders is discharged in such a manner as to intensify the draught through the tubes, the vapours from which are taken with the steam in one rushing blast up the chimney. In a marine engine, although there is not the absolute impossibility, as in a locomotive, of having outer flues of brickwork, it may be considered practically impossible. As, however, in marine engines, there is seldom a blast to stimulate the draught and keep the tubes free from cinders, and as the tubes cannot be cleaned so often as in a land boiler, the tubes are made larger and shorter, a diameter of about 3½ in. being usual, while in locomotive or portable engines the tubes are seldom larger than two inches.

Have great heating surfaces and produce steam rapidly.

Are self-contained and need no brickwork.

Advantages.

Used in locomotives.

See CHAP. XXII.

The steam blast.

See also page 184.

Marine boilers.

Have larger and shorter tubes.

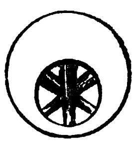
In a portable engine, the importance of having a boiler sufficiently small, and the impossibility of having outside flues of brickwork, render the multitubular boilers almost as necessary as in a locomotive. In these three important kinds of engines, therefore—the Locomotive, the Marine, and the Portable—there can be no difference of opinion as to the propriety of using multitubular boilers. But in regard to stationary engines, opinions are divided. Multitubular boilers are self-contained, need have no outside setting,

Boilers of portable engines.

See page 183.

and though tubes have periodically to be replaced, such boilers hardly ever explode. **Drawbacks to multitubular boilers.** On the other hand they cost more than Cornish boilers, require repairs more frequently, are less accessible for repairs and cleaning, and do not last so long. **Less durable than Cornish boilers.** The furnace, fire-box, and tubes, and their connecting parts, have to endure fiercer and more concentrated heat than the simpler parts of a larger Cornish or Lancashire boiler. **Other inconveniences.** The inconvenience and loss which are occasioned by the bursting of a tube, or by any other mishap which involves the temporary stoppage of the engine, together with the trouble and expense of replacing a worn-out boiler by a new one, disincline many users of steam-engines from multitubular boilers, and lead them to prefer the Cornish type of boiler. **How neutralized.** These inconveniences can be, and often are, largely neutralized by having one or more **Spare boilers.** spare boilers ready for use during the repair or replacement of a defective one; *See page 180.* and the capital sunk in such extra boilers must be considered as an investment, for which the compensations obtained are a sufficient return. In stationary engines, however, there is not the same limited space as in the engines just now alluded to; and it is in such cases, where there is ample room for external brick flues, **Cornish boilers best for fixed engines.** that Cornish boilers appear to the best advantage; and, when well arranged, consume less fuel than those "self-contained" multitubular boilers without external flues. But there is a growing tendency towards the use of high-pressure steam and quick-speed engines, and it is sometimes difficult in a Cornish boiler, unless it be made of excessive size, to maintain a sufficient supply of steam. Moreover, the small size of multitubular boilers, not only renders them stronger than the larger Cornish boilers, but they are of less weight, and occupy less space. **Relative cost of boilers.** When a Cornish boiler for a 20-horse power engine would cost, complete with fittings, £180, a multitubular boiler would probably cost about £250, but the latter may, if desired, be arranged with little or no brickwork.

Both kinds combined. Such opposing conditions have suggested many expedients, which have generally taken the shape of some compromise between the two kinds of boilers. In some Cornish or Lancashire boilers, vertical or diagonal tubes are inserted across and through the ordinary tubes, by which plan the effective heating surface is much increased, a beneficial circulation of the water promoted, a more rapid generation of steam caused, and the main tubes are strengthened against collapse. In other cases, a boiler of a hybrid kind is constructed with the furnace and parts adjacent of the Cornish form, and the further part multi-



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Cross Tubes.

tubular. In both these cases the parts are more accessible than in an ordinary multitubular boiler; the small tubes are not exposed to so fierce a heat; and there is the same advantage as in an ordinary Cornish boiler, of having external flues of brickwork. If the latter are adopted, the heated vapours, after leaving the internal tubes, can be effectively conveyed round the outside of the boiler, and the minimum allowed to pass up the chimney in waste. With a properly proportioned grate-surface, and by careful stoking, the consumption of fuel in such boilers can be kept as low as in any known kind of boiler. Cross tubes, as above described, are now generally inserted in the furnaces of small self-contained vertical boilers used for steam-cranes, winches, and similar purposes, instead of such boilers being made multitubular, as it is found that the numerous small tubes, which the latter system involves, are, in so confined a space, liable to be choked up and to burn away. In the small boilers used for these purposes, it is impossible to prevent the escape through the chimney of heated vapour which in larger boilers might be utilized; but as no other kind of boiler is practicable, the great convenience and saving which such engines afford, as compared with manual force, justify the great consumption of fuel which takes place.

Hybrid boilers.

Boilers for small engines.

See CRANES.

Consume much fuel.

Boilers composed entirely of tubes, form a special class distinct from those mentioned. The tubes are suspended vertically and near together in rows in a brick furnace, and each row of tubes is joined at the top to a horizontal tube, several of which, forming a series of steam-chambers, are joined to one large cross tube. A very large heating surface is presented by the groups of pendulous tubes to the flames and vapours of the furnace; and there is the additional peculiarity that the vertical tubes are all double or annular. The inner tube opens to the outer one at the bottom, and there is a constant circulation of the water, which assists greatly the rapid generating of the steam. There are different applications of this system of annular tubes grouped together; in some the tubes are of cast-iron, in others of wrought-iron, the diameter ranging from 9 in. to 2 in. The special advantages claimed for these boilers by their inventors are that they heat water very quickly and cheaply, because of the large heating surface they present, and the peculiar circulation of the water; that they are very portable when taken to pieces; and, most important of all, that they are absolutely free from dangerous explosion because of their subdivision, since the bursting of any one tube would cause inconvenience only, and not disaster. The chief objections to these

Boilers made entirely of tubes.

Pendulous tubes.

Annular tubes.

Advantages.

Drawbacks. boilers are the numerous points liable to leakage, and to become foul with bad or dirty water; and the trouble to the user of putting the pieces together. They have not been preferred to other boilers to the extent anticipated.

Opposing conditions in choice of boilers. But so long as engineers or users of steam-power are met by opposing conditions—as for instance, on the one hand, by a limited space or the need for a self-contained boiler independent of all brickwork, or for one which will generate steam very quickly; and on the other hand, by the inconvenience of tubes or complications requiring frequent cleansing, repairs, or renewals—there will remain for consideration how best these conditions can be reconciled, and the best result attained. **Choice depends on varying circumstances.** The conflicting merits and demerits of different kinds of boilers can only be weighed and a proper choice arrived at, on the basis of the circumstances enumerated on page 181. Whatever boiler may be adopted, the amount of fuel consumed will of course much depend upon its quality, on the proper air-spacing of the fire-bars, and on the efficiency of the stoking. Conversely, the kind of fuel which will **Different kinds of coal.** be most effective depends upon the form of the boiler, the shape and size of the furnace, and on the draught. *See* COAL, *page 118.* Some kinds of coal demand a great draught; there are others in which combustion must be checked; and if certain kinds of fuel are more easily obtained than others, it is very important that the boiler should be constructed accordingly.

Boilers tested, Hydraulic test. Steam test. It is usual in the purchase of boilers to have them tested before leaving the manufactory, a test with water to double the intended working pressure, and a subsequent test with steam to the maximum working pressure being usual. But tests of this kind, though proving the absence of gross faults in workmanship, and of flaws in the iron, do not alone prove the sufficiency of the boiler for long service. Boilers have to endure not only the pressure outwards of the steam, but severe strains from the alternate expansion and contraction of the iron when hot and cold, and also the action of the fire upon the plates in and about the furnace. As it is important to have a sufficient margin of safety against these contingencies, it is usual to **Thickness and quality of iron specified.** stipulate for a certain thickness and quality of iron; and makers in stating their prices may be called upon to specify these points. In certain parts of the boiler the quality of the iron is sufficiently proved by its enduring the flanging, bending, and other treatment during manufacture, but superior iron is generally used also for parts exposed to the fire. The value of a boiler depends also on the thickness of

the plates and their consequent durability when exposed to wasting and corrosion; and thin plates are not only cheaper to the maker, but allow of bending and other operations with inferior iron.

Classification of steam-engines.

Stationary Steam-engines may be divided into three kinds, and placed in the following order: non-condensing-engines, condensing-engines, compound-engines. For the first of these, the ordinary name was formerly "high-pressure" engine, because since its power was derived directly from the steam, instead of from the vacuum produced in a condenser, higher pressure was employed than in the latter case. But now that high-pressure steam is used in condensing engines, the term is not sufficiently distinctive and often misleads. The vast majority of engines now made are non-condensing, the additional apparatus required in a condensing-engine occupying space, while it renders the machine more complicated and expensive. In a locomotive (with a few special exceptions which need not here be described), the limited space would alone render a condenser impossible; and the same objection applies with almost equal force in portable engines of all kinds. In a marine engine, different conditions determine a choice, for, unlike the locomotive which need only carry coal for a few hours' consumption, a large supply has to be carried, the space occupied by which is very valuable. The economy in coal, and therefore in the stowage space for coal, which condensing engines allow, far exceeds the value of the extra space which a condensing apparatus occupies, and therefore, as water is abundant for injection or surface condensation, condensing engines are used in all steamers, except small boats for river or harbour service, which can take in fresh coal as often as a locomotive.

High-pressure or non-condensing-engines.

Are simplest and cheapest.

See page 162.

Marine engines always condensing.

Exceptions.

Non-condensing-engines were, up to about the year 1850, generally worked at a pressure of from 25 to 40 lbs. per square inch; and the steam, after being admitted to the cylinder during nearly the whole of the stroke, was discharged into the atmosphere, at a considerable and therefore wasteful pressure. Boilers and engines had to be made of large size to produce a given power, and the consumption of fuel was excessive. It was found, however, that boilers could as easily be made strong enough for high as for low pressure, and the practice of using steam expansively became general. It is a matter of the simplest demonstration, that steam worked expansively, that is to say, high-pressure steam admitted to a cylinder for only a portion of the stroke—one-third, one-fourth, or one-sixth, as occasion may require—and then,

Low-pressure steam.

Wasteful.

High pressure adopted.

Expansion of steam advantageous.

the supply from the boiler being shut off, allowed to expand into the increasing space left by the advancing piston, will, by such a method, produce a given power with far greater economy than is possible with the old system. Steam of 70 and 80 lbs. is now (1880) commonly used in stationary engines; and the advantages obtained are so considerable, that probably even greater pressure will become general. The principal expenditure of fuel is that incurred in the raising of cold water to a boiling point, that for raising the heat and pressure further being less in proportion. In other words, it does not require twice as much fuel to produce a pressure of 80 lbs. as for 40 lbs., the temperature of steam at 80 lbs. pressure being only 37° higher than that of steam at 40 lbs. Moreover, space is saved by obtaining the best effect from an engine of given size, and the additional cost for making the various parts strong enough for the power given, is small compared with the advantages gained.

Usual high pressure.

Saves fuel.

Locomotives, in which great power has to be concentrated into small space, are worked at from 120 to 160 lbs. per inch; but this requires a forcing of the combustion, which does not tend to economy in fuel, and is not expedient therefore for ordinary fixed engines. At present (1880) it may be stated as an axiom, that non-condensing stationary engines should not, if economy be desired, be worked at less than 60 lbs., and that a pressure of 80 lbs. is still better, the boiler and other parts being of course suitably constructed. The use now of higher-pressure steam than formerly, enhances the value of those precautions which are necessary to prevent waste by premature condensation. Steam as it leaves the boiler always contains more or less water, as shown in extreme cases by "priming;" and however much the pipes and other parts may be enveloped in material which is a non-conductor of heat, condensation takes place which increases the amount of water in the steam, and there is a loss of pressure which implies a corresponding loss of fuel. To counteract this condensation, the principle of superheating was introduced. This consists in increasing the temperature of the steam after it leaves the boiler, so as to transform into steam the globules of water held in suspension, and beyond this, to dry or superheat the steam to a higher temperature than that which corresponds to its elastic force; and this extra store of heat compensates for the loss, which in any case it must undergo, in transmission to the engine; and also tends to prevent the condensation of the steam during the expansion in the cylinder. Various forms of apparatus have been used for superheating steam, but in

Usual pressure in locomotives.

See Chap. XXII.

In stationary engines.

Priming of boilers.

Superheating. Explained.

How effected.

most of them it is sought to conduct the steam, in its passage from the boiler to the engine, through pipes or vessels heated by the waste vapours from the furnace. It has been found, however, that steam superheated beyond a certain point damages the valves, pistons, packing, and other working parts of the engine; and for these reasons, the application of this system, even within safe bounds, has been greatly limited. A step in the same direction is the making of engine cylinders with steam jackets, or, in other words, giving them a double shell, so that when the annular space between the shells is filled with steam, a high temperature inside the cylinder is maintained, thus preventing the partial condensation which the steam inside the cylinder undergoes when brought into contact with a surface of a temperature less than its own. Superheating is principally practised in marine engines, but steam-jacketting is commonly adopted on marine, stationary, and portable engines.

Application of system limited.

Steam jackets.

Where adopted.

A certain stage in the path of economy having been reached by using high-pressure steam expansively, and by steam-jacketting the cylinders, the next step forward has been to use high-pressure steam in condensing-engines. Although the first cost is greater, and more space is required, and more working parts are rendered necessary, the economy in fuel which the use of condensers allows, far more than outweighs these drawbacks in the majority of cases. It is not too much to say that the consumption of fuel can at once be reduced by from 20 to 50 per cent. by using a condenser in a high-pressure engine such as just described. Small engines are not, however, usually so made, and 12-horse power may be stated as about the point at which condensing engines commence. As, however, the gain (which ranges from 12 lbs. to 14 lbs. per square inch) afforded by condensation is less in proportion to the total force as the pressure of steam is increased, condensers are seldom applied to engines working with more than 60 lbs. steam pressure.

High-pressure condensing-engine.

More costly.

But saves fuel.

See page 162.

Not suited to small engines or very high pressure.

The strict analysis to which the operations of a steam-engine have been subjected in all its parts, and the unprofitable consumption of fuel which such analysis discloses, have led to the closer appreciation of the conditions of economy; and in this direction the introduction of compound-engines may be considered as the latest improvement made up to the year 1880. The principle of the compound-engine is the combination of a high-pressure non-condensing-engine, worked expansively, with a condensing-engine; the exhaust steam from the non-condensing cylinder, instead of being discharged into

Compound-engines.

Described.

the atmosphere and lost, being transferred at its reduced but still effective pressure into the second cylinder worked on the condensing system. This method became generally known about 1850 (Wolf's system was known much earlier) and its adaptation to marine engines took place about 15 years later. Several kinds of compound-engines are used; but they may be broadly divided into those in which there are two separate engines, the condensing and the non-condensing, working side by side; and those in which the two cylinders are combined in one engine. The latter may be taken as, perhaps, the more perfect, and the less expensive in the majority of cases. For sea-going steam-ships, where the stowage of the coal as well as its cost is important, compound-engines may be said to be now universally adopted.

Different methods.

Chiefly used in steam-ships.

It has been attempted, but up to 1880 not on a wide scale, to apply detached condensers even to small non-condensing-engines where a good supply of water can be obtained, so as at once to increase the power of the engine, or reduce the consumption of fuel. The condenser may be placed in any convenient situation, as far as 50 ft. from the engine; the air pumps attached to the condenser can be driven by belt from a line of shafting, the exhaust steam being brought to it by a line of pipe. These condensers cost from about £25 for an 8-horse-power engine, to £100 for a 40-horse-power engine; and if necessary, the exhaust-steam of more than one engine can be taken to the same condenser. For stationary engines in foreign countries, it is not always desirable to use condensers, and local circumstances such as are enumerated on page 181, must determine which kind is to be preferred.

Detached condensers.

How applied.

Cost.

Not always expedient.

Another classification of steam-engines is according to their shape. The rocking-beam was the form in use for pumping-engines when Watt commenced his career, and it was this form of engine which he adopted, and in which he introduced all his improvements. The ease and smoothness of action in a beam-engine render it perhaps the most enduring of all, and the vertical cylinder, in which the piston wears more equably than in a horizontal engine, is an advantage valued by some engineers. In cases where a steam-engine is required for regular, unchanging, and permanent work, at moderate speed, and especially also where a breakdown would be attended with disaster—all of which conditions are, for instance, met with in the case of a pumping-engine for supplying a town with water, or in the blowing-engine for a blast furnace—many engineers still prefer the beam-engine; but

Engines classified according to shape.

Beam-engines.

Advantages.

Where used.

See page 201.

beam-engines are not adapted for the high speeds which, for other purposes, are found advantageous in modern practice. It was formerly the custom in spinning factories, engineering workshops, and similar cases, to transmit the power of the engine from the fly-wheel by belts or gearing, which increased the speed, but it is now considered better to work the engine itself at the higher speed and to continue the main shaft direct into the factory. This practice alone leads often to the substitution of horizontal engines. Beam-engines are generally made with condensing apparatus; they are seldom made smaller than 16-horse power; they cost from one-fourth to one-half more than horizontal engines; and longer time is required for making them. Beam-engines not only cost more, but they also require more expensive buildings and foundations; and it may be stated, as an almost universal opinion of modern engineers, that beam-engines do not offer advantages sufficient to justify their cost, and they are every year becoming fewer, in proportion to other kinds.

Not suitable for high speeds.

As condensing engines.

Are costly.

Are less used than formerly.

Horizontal engines, of which more are made than of all other kinds put together, are simple and compact; they lie low and steadily on a level foundation easily constructed, and are cheap. They are the kind now most frequently adopted, even for pumping from mines, where beam-engines were formerly universally used. For winding from mines horizontal engines are also chiefly used, and are fitted with sensitive valves, reversing-gear, and powerful brakes, so that though they run at a high speed, they can be easily stopped and reversed. The ordinary type of horizontal engines may be described as having a long cast-iron bed-plate, on which the cylinder, guides, and plummer-blocks are bolted; the bearing-surfaces on the bed for all these parts being in the process of manufacture conveniently planed at one operation. The feed-pump is in some placed vertically under the crank shaft, from which the necessary power is taken by an eccentric; in other cases, the feed-pump is placed horizontally by the side of the guides on the bed-plate, and worked by the piston cross-head. The pump is more accessible by the latter plan, but if breakage takes place it is more inconvenient there than by the former plan. The above form of engine is usually adopted for sizes between 10 and 60 horse-power. Horizontal engines of this kind cost from £12 to £14 per nominal horse-power for sizes between 8 and 20 horse-power, and the cost decreases per horse-power as the size increases, so that with an engine of 50-horse power, the cost would only be about £10 per

Horizontal engines.

See page 202.

As winding engines.

Ordinary type.

Position of feed-pump.

Cost of horizontal engines.

Extra charges.

See also page 180.

horse-power. The exact price at any time varies, not only with the cost of materials and labour, but with the number of extra fittings required. Thus, a link-motion reversing gear, as for winding-engines, or special pulleys or drums, involve extra charges. The above prices are for engines only, and the cost of Cornish or Lancashire boilers with their fittings and connections is, for the smaller sizes, more than that of the engine; but above 12-horse power, the proportionate cost of boiler becomes rather less. There is however, no fixed relation between the prices of engines and boilers, as obviously much depends on the kind of boilers, and the other circumstances of each case. Engines up to 20-horse power, can either be purchased ready made, or can soon be finished when ordered. But engines of higher power are seldom made except as ordered, and the manufacture generally requires from two to four months' time. Where condensing-engines are made of the horizontal form, the condenser is either placed at the outer end of the bed-plate, and the air-pump and injector-pump worked by an extension of the piston-rod; or the condensing apparatus is placed below the bed-plate, and the pumps worked by a small rocking-beam, bell-crank, or quadrant. There are numerous arrangements differing in detail according to both these plans.

Cost of boilers.

Small engines purchased ready made.

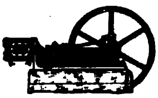
Position of condenser.

Engines above 50 H. P. made in pairs.

When more than 50-horse power is required, the question arises whether a pair of engines is not preferable; and it becomes difficult to suggest rules for guidance which are not likely to mislead, as in almost all such cases there are special circumstances which have to be considered. Where there is a likelihood of increased power becoming necessary in the future, the engine-house and foundations may be constructed with a view to the after addition of a second engine to the crank-shaft of the first; and the crank-shaft may be made long enough for such addition, and strong enough to transmit the additional power.

Or second engine added.

Cheap horizontal engines.



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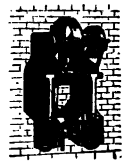
The great demand for horizontal steam-engines of small power has led several manufacturers to establish standard patterns of their own, which by constant repetition can be made very cheaply. The parts are few and simple; the bed-plate is short, because the cylinder overhangs, and one principal casting suffices for bed-plate, guides, and plummer-block. This form of engine is chiefly adopted for sizes between 3 and 20 horse-power, any of which can be purchased ready-made, for about 20 per cent. less than the horizontal engines just described.

Vertical engines.

Save floor space,

Vertical engines are very useful where floor area is limited, as considerable power can be obtained in a small space. But unless the walls can be utilised for the attachments, wide base-plates are needed, and the foundations are more expensive than those for horizontal engines. Small vertical engines are made in various forms, as detached engines with separate boilers, or as complete self-contained semi-portable machines with boiler and engine in one. Wall-engines may be described as horizontal engines placed vertically, and bolted to a wall instead of to the ground, as the general arrangement of the parts is in other respects similar. When a strong wall is available this mode of fixing the engine is often very useful, as the crank-shaft can be continued directly as a line of shafting at a convenient height from the ground. It is becoming usual, in large engineering factories where there are numerous machines, to erect several small engines instead of one large engine, so that the machinery in any one department can, if necessary, be kept going without working the whole engine power, thus reducing the inconvenience from accidents by dividing the risks over numerous engines. In cases like these, where there is a range of workshops side by side, the engines working in each gable wall may be made a symmetrical feature in the architectural design. Wall-engines cost about the same as horizontal engines.

Wall-engines.



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See page 75: also FACTORIES, *Chap. XVI.*

MACHINE-TOOLS, *Chap. XXIII.*

Rotary engines.

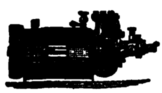
Ever since steam-engines were first introduced, there have been constant attempts among inventors to design an effective *Rotary* steam-engine; and the problem is a fascinating one, because a continuous circular motion is obviously more desirable—if it can be satisfactorily obtained—than a reciprocating motion which has to be changed into a circular one. Although many rotary engines have proved successful in the sense that they have done effective work, none of those invented up to the year 1880 are likely to supersede the ordinary types of engines; and of the best it must be said, that while they are ingenious and novel, they afford no real saving as compared with other and more usual engines. Many of these machines are more effective as force-pumps than steam-engines, but even in these respects novelty and ingenuity recommend them, rather than any superiority over other kinds of pumps.

Not successful.

See page 207.

3-cylinder engines.

The compactness which the rotary engines if successful would afford, has been obtained by an ingenious application of the ordinary reciprocating piston. Brotherhood's engines have three steam cylinders arranged round one shaft, to which the three pistons converge, and to the one crank of which they give motion. The crank-



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shaft can be continued directly from the engine as a line of shafting, or the power can be transmitted from a pulley on the crank-shaft in the ordinary way. The pistons are single-acting, the steam being admitted only on the hinder side; and as the pistons are made deep enough to guide themselves in the cylinders, the connecting-rods are hinged directly on to the piston, after the manner of trunk-engines. As there is no "dead centre," a fly-wheel is unnecessary, and the connecting-rods being always in compression, the engine runs more smoothly than is possible in the case of an ordinary engine where the connecting-rod is alternately pushing and pulling the crank-pin. As the stroke of the pistons is very short, a moderate piston-speed per minute allows considerable velocity, so that the engines can be attached directly to such machines as fans, circular saws, dynamo-electric, or centrifugal machines, and also to the screw propellers of steam launches. The engine can be easily reversed while running, and the valves are so arranged as to allow of the steam being worked to any degree of expansion; but those above 10-horse power do not allow so great an economy of fuel as fixed engines. Their compact shape and few parts allow them to be made cheaply, so that they can be purchased at a price less than that of a horizontal engine of the same indicated horse-power, calculated on a steam-pressure and piston-speed alike in both cases. These 3-cylinder engines have been very successful since their introduction, and besides their use at ordinary pressures for the purposes named above, have been applied in a peculiar way to the concentration of great force in a small space for propelling fish-torpedoes. Air compressed till it affords an expansive force of 1,500 lbs. per square inch is used instead of steam, and by this means an engine weighing only 30 lbs. can be made to exert, for a few minutes or more (according to the size of the air reservoir) a force equal to 50 indicated horse-power. While, however, engines worked by high-pressure air may be useful in special cases, the trouble and expense of compression forbids their use for ordinary purposes. These 3-cylinder engines can also be worked by water, either as original motors or with force concentrated by an accumulator.

Mode of working. **Run smoothly and quickly.** **How applied.** **Advantages.** **Compact and cheap.** **Concentrated force by compressed air in torpedo engines.** *See page 94.*

Catalogues and price lists.

The publication of catalogues and price-lists has done much to remove the mystery which formerly attended the manufacture of steam-engines, and has greatly extended the facilities for export. The commerce in engines of uniform pattern also allows the use of special

tools and economical methods. Formerly, engines were designed only for their ultimate purpose, and machinery was applied to the manufacture, only so far as the shape of the various parts permitted; now, to a considerable extent, the tools and methods are the starting point, and the parts of the steam-engine are designed to meet their capacity. The use of the lathe has especially been extended, and operations formerly performed by hand-labour, or by slowly-working planing-machines, are now more quickly accomplished by rotary motion. The uniformity which cheapens price does not, however, allow of such exact adaptation to the purpose in view, as is possible where each engine is made specially; for the shape and dimensions offered by the manufacturer must be accepted; and alterations, if demanded, generally involve an extra cost, out of proportion to the advantages obtained. There are, however, certain modifications which manufacturers allow, with little or no addition to the price—such as making the engine right or left-handed, and altering the position, or diameter, or weight of the fly-wheel.

Engines of uniform kind.

See LATHES, *Chap. XXIII.*

Uniformity not always convenient.

Modification allowed.

See also page 187.

The diversity afforded by the catalogues of numerous manufacturers, often enables a purchaser to obtain an engine suited to his purpose; but the number of manufacturers who are on equal terms in regard to quality is very limited. The custom of buying from catalogues is followed mostly for steam-engines of less than 20-horse power; for as the number of engines of similar kind that can be sold becomes rapidly less when 10-horse power is exceeded, manufacturers are seldom disposed to keep large engines in stock; and, moreover, the necessity for variations of established patterns and dimensions, and the expense of obtaining them, become greater as the power increases. Engines beyond 20-horse power are therefore seldom kept ready made, but are made to suit exactly the purpose of the purchaser. As, however, a considerable portion of the original cost of an engine is that for drawings, templates, and foundry-patterns, manufacturers always endeavour to utilise those they have; and it is almost always advantageous for purchasers to adopt such patterns. Not only is the cost so reduced, but manufacturers and their workmen do best what they are accustomed to do. For this latter reason, it is generally inexpedient to present to one manufacturer the designs of another for production; a course sometimes followed by those who wish for competitive prices. Where not only a general design or shape which is freely open to imitation is so transferred, but details which have been obtained from the rival manufacturer are supplied, such a course is also unfair.

Diversity of engine.

Ready-made engines.

Seldom exceed 20 H. P.

Standard patterns

Accustomed kinds cheapest and best.

See page 24.

See page

Dimensions of engine stated by seller.

See page 161.

See page 168.

Also the assumed pressure and speed.

See page 160.

It is usual in the commerce in steam-engines, for the manufacturer to state the leading dimensions to the purchaser, or, at any rate, the diameter of the cylinder and the length of the stroke, because these dimensions, with a given working pressure of steam, afford an approximate measure of power and value. The particulars which determine the value of the boiler have been already described. The manufacturer should be called upon to state the pressure of steam and rate of speed which he recommends and on which he has based his calculations, and it is generally desirable to adopt these in the actual working. Particulars of this sort are frequently given even in the printed catalogues of engine-makers; and when the purchaser is satisfied with the reputation of the manufacturer, he requires no more.

Other particulars required.

See page 13.

Difficulty of comparing tenders.

By weight.

Not conclusive.

Examination and inspection.

Engine tested by actual working.

See pp. 3, 7, 12, 13.

But where the engine is one offered by the seller for a particular purpose, and especially where the expenditure involved is considerable, it is usual to give other dimensions also, and to enumerate the various accessories. But while these points do much to allow an appraisement of value and a comparison of prices, the responsibility for their fitness for the proclaimed purpose, should be left with the manufacturer. But unless there be some knowledge of, and confidence in, the seller, it is almost impossible to decide as to the comparative merits of various tenders. In some cases, if the weight to be supplied could be ascertained, it would immediately disclose that one maker intended to give a machine more solid and substantial than another. On the other hand, if strength is to be obtained by thickness and weight of parts, rather than by excellence of material and design, such a comparison will mislead, for mere weight may be given on account of doubt or errors in design, may involve undue friction in working, consume excessive power, and may be allied with rough workmanship. An examination in the first instance by an engineer of the drawing and specification, and an inspection afterwards of the workmanship and movement under steam, may in many cases be the only sure tests. It is for the above reasons that there is generally so much wider divergence in numerous tenders for steam-engines and machinery designed by the respective competitors than in those tenders based upon some common design or bill of quantities.

Engines fixed and tested *in situ* by maker.

When a stationary engine is bought for use in the country of manufacture, the maker is generally employed to fix it in place, and to verify, by running it under steam, the accurate fitting of the moving and bearing parts. For export, engines not exceeding 20-horse power can generally be so tested in the factory, and this should be made a

condition of purchase. The engines should be worked continually at full speed for several hours, and then the piston, slide-valve, and other wearing parts examined, and, if necessary, eased or adjusted. Preparatory working of this sort sometimes affords an opportunity for measuring the strength of the engine, but such a trial demands very great care and watchfulness to render it trustworthy, and if the engine has been properly made the dimensions and steam pressure will sufficiently demonstrate the available power.

Or tested at factory when for export.

Engines of the same nominal power differ so widely in design and workmanship, that a mere comparison of price is worthless as a measure of cheapness. Among the circumstances which should determine a choice, the following almost always apply :—

Cheapness not to be measured by price.

The stroke of the engine should be long enough to afford the desired power, at a proper piston-speed without an excessive number of revolutions. As a general rule, it may be said that high speed gives the greatest power for a given size of engine, and that a moderate speed gives the best results for a given expenditure of fuel.

Other circumstances.

Length of stroke.

Speed.

The slide-valve gear should not only allow for the use of steam expansively, but should be capable of adjustment; and the apparatus for doing this should be simple for the engine-driver, and not liable to become deranged. The governor or other arrangement for regulating the speed should be automatic.

Adjustability.

The framework and fixed parts of the engine should be strong; the joining surfaces well machined, and the bolts tightly fitted, so as to prevent the parts of the engine shaking loose or out of true line.

Strength of framing.

The bearings and other moving parts should be of ample area, and so well fitted as to cause the minimum of friction in working.

Bearings.

Provision should be made in wearing-parts like the guide-bars for adjustment and taking up the wear.

Wearing parts.

Certain parts of the engine, such as the piston-rod, connecting-rod, and crank, should be made of high-quality wrought-iron or steel; and there should be a proper amount of gun-metal (brass) in the bearings and other parts.

Use of steel and gun-metal.

The moving joints, such as in the link-motion, valve-gear, and governor, should have steeled surfaces, or be case-hardened, so as not to wear loose. Although assurances as to case-hardening are almost always given by engine-makers, it is a troublesome operation often imperfectly performed; but when properly done it adds greatly to the durability of the engine, for it renders the surfaces as hard as the hardest steel, without the accompanying brittleness.

Case-hardening of joints.

Extra parts and fittings. **Vary according to purpose.** **Insufficient information.** *See page 49.*

It almost always happens in the setting to work of a steam-engine that extra parts or fittings are needed beyond those actually pertaining to the engine, and the mere printed price of a manufacturer or dealer seldom includes more than the engine itself, for as the accessories or extra parts vary with each engine, the price must be determined by the necessities of each case. An engineer or manufacturer who is consulted by a purchaser, and made fully acquainted with his wants, ought to specify and enumerate all that is required; but very often prices or tenders are based on insufficient particulars: this most frequently happening with inquiries from abroad. As the price of the engine alone may form but a small proportion of the whole expenditure, and a tender apparently the cheapest prove afterwards to be the dearest, it is very desirable at the commencement to ascertain and describe everything that is wanted, so that one contract may serve for all.

Steam pipes extra. **Reversing gear.** **Secondary shafts.** **Special extras.**

Unless otherwise specified, a steam-engine, if without boiler, does not include any piping, and even when a boiler also is purchased, close contiguity of boiler and engine is assumed, and only the pipes necessary under such circumstances included. The extra parts, which vary in almost every case—but of which some or all are generally required—are the steam-pipes between engine and boiler, exhaust-steam pipes, suction and delivery pipes for feed-water, and the holding-down bolts; and all of these differ according to the arrangement and dimensions of the buildings and foundations. Link-motion reversing-gear, as necessary for a winding-engine, is not supplied except where it, or the purpose which would render it essential, is specified; nor are secondary shafts, wheels, or pulleys, for transmitting the power of the engine. Among other additional parts which may be required and which involve extra cost, are peculiar or sensitive governors, safety-valves, or automatic regulating apparatus of a novel or exceptional kind. The extra parts are sometimes entirely outside the special functions of an engine-maker; girders, columns, or other structural ironwork in connection with the building, being frequently required.

Duplicate parts. *See pages 40 and 166.* **Specially needed in distant countries.**

The supplying of duplicate parts is a question quite distinct from the foregoing, and one that depends principally on the destination of the engine, and the facilities for obtaining what is wanted, as the need arises. Few or no duplicate parts need be purchased with engines for use in the country of manufacture, but for distant countries it is usual to purchase with the engine spare bearing-brasses, fire-bars,

and even a spare piston; while in cases where the temporary failure of the engine would involve great loss or inconvenience, a duplicate engine is kept ready for working; and it is a common precaution—even in the country of manufacture—to have one or more spare boilers available for use while those that have been working are being cleaned or repaired. **Spare boilers.**

The carriage of an engine to its destination often involves trouble and expense, and especially so if the engine be one of considerable power, or if the means of transport be limited. But while it may save much cost in carriage to have small or light pieces, such economy may be too dearly purchased. For instance, it is a great advantage to have an engine bed-plate in one piece, so as to ensure solidity and firmness in all the parts connected to it; and a double rate of carriage may be amply justified to prevent the division of such a piece. Or sometimes an engine may be sent almost entire, with cylinder fixed and slide-valve adjusted. The skilled labour in re-erection, which division for transport of such parts renders necessary, is sometimes very expensive. Thus a boiler, if divided into pieces, not only cannot be tested satisfactorily at the manufactory, but requires skill, not always available at the site of erection, for riveting and caulking the joints. **Carriage to site.** **Size and weight of pieces.** *See pages 35 and 40.* **Skilled labour to erect engines.** *See page 40.*

In a well-designed engine the parts are kept as light as is consistent with strength, not only to save expense in manufacture, but to reduce to a minimum the weight of the machine and the power necessary to work it. But in engines made for export to foreign countries, where repairs are not easily executed, and where the inconvenience or loss from a "break-down" are serious, the ordinary margin of safety may sometimes be increased with advantage. **Lightness of parts.** **Extra strength required abroad.** *See page 42.*

The kind of steam-engine which is best suited for export to a foreign country can only be properly determined on the basis of the following particulars, of which, some or all, as they may be found to apply to a particular case, should be furnished by the purchaser. **Choice of engine, how determined.**

1. The purpose for which the engine is required, and how far it is for temporary or permanent use. **Purpose.**

2. The power required, or such particulars of the service as will allow the power to be calculated by an engineer. **Power.**

3. The kind of engine and boiler already in use in the country, or to which the workmen are accustomed. Local reasons for or against any particular kind. **Accustomed kind.**

4. The space available for the engine and boiler, and its level as regards the ground, floor, or other datum. If the space be limited, a **Space available.**

plan and section should be provided so as to show whether it is length, width, or height that is limited. If a vertical engine be required, the walls or buildings available for attachment, should be described.

Connections needed.

5. So much description of the machinery to be driven and its speed as will allow a proper provision to be made for connecting it to the engine, or transmitting the power. If the machinery is already provided, sketches and dimensions of the shafts, wheels, or pulleys to which connection is to be made, must be given, and their speeds.

Arrangements for transmitting power.

If there is any reason why the engine should be right or left-handed, (the crank-shaft on the right or left side, looking from the cylinder), it should be stated.

Buildings.

6. A description of the building in which the engine is to be fixed, or if a house, chimney and foundations have to be designed, particulars of the building and roofing materials available. The nature of the soil on which the engine and boiler house are to be built; whether the soil is dry, or can be drained; whether it is liable to floods; and all particulars by which the level and nature of the foundations can be decided.

Foundations. *See page 62.*

Kind of fuel. *See page 127.*

7. The kind of fuel which is to be used, and its kind and quality as compared with some standard English coal. If coal is not obtainable, a description should be given of the wood, saw-dust, peat, oil, straw, or refuse available, and their comparative cost and abundance.

Kind of water.

8. The water available for the boiler, or for a condenser; its quality and abundance; the level or situation of the reservoirs in regard to the engine; whether in a well, pond, river, tank, cr in pipes.

Nature of supply.

If from some public source, the head or pressure; if to be purchased, the cost of the water, and how it is measured.

Carriage to site. *See page 39.*

9. The facilities for landing machinery at the port of arrival, especially for heavy or bulky pieces; the import duties payable, and how assessed; the nature of the roads and means of transport from the port of arrival to the site.

Workmen. *See page 40. Also page 40, Part I.*

10. The kind of workmen available for erecting the machinery, for acting as engine-drivers and stokers, or as mechanics for making repairs.

Workshops and facilities for repairs. *See pages 40–42.*

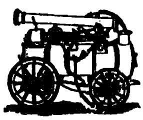
11. The kind of engineering factories, foundries, or workshops—if any—available for repairing or replacing damaged or worn-out parts, and the time which would be needed to import fresh parts. The importance or otherwise of keeping the machinery always at work, and the periods of rest available for repairs. This information is necessary, not only to the proper choice of engine and boiler, but for deciding

on the duplicate parts which shall be provided. In the case of large engines with heavy pieces, particulars should be furnished of the tools and plant available in the country, such as cranes and winches, and engineers' tools for fixing the engine in place.

See Chap. XVII. TRANSMISSION OF POWER. *See page 91.*

There are cases where a steam-engine cannot apparently be applied, but under certain circumstances it may be possible and expedient to bring steam from a considerable distance; and compressed air or water may even be used to work an engine originally constructed for steam.

Portable engines.



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Portable Engines (*locomobiles*), introduced first for agriculturists, are employed for a variety of purposes, in all parts of the world. They are shaped like a locomotive, and have also a multitubular boiler, but the engine is fixed upon, and not beneath, the boiler. Portable engines are usually made with one cylinder only up to 10-horse power, and above 12-horse power always with two cylinders. The double-cylinder arrangement has the advantage of distributing the strains from the engine better on the boiler, and of giving a more equable motion. Although portable engines are made up to 30-horse power, their use becomes of doubtful expediency beyond 20-horse power, **Maximum power.** and the great majority of those made are between 6 and 12 horse-power. Fitted with wheels and axles like an ordinary wagon, the portable engines can be drawn from place to place by horses; **Drawn by horses.** and being complete and self-contained can be set to work at any time. The inconvenience of providing horses for drawing them has led in many cases to the substitution of self-propelling gear on the engine itself. **Or propelled by steam.** This arrangement is, however, subsidiary, and not of primary importance as in a traction engine. *See page 189.* No special skill is required to manage portable engines, and experience has proved them to be very free from liability to accident. In agriculture, portable engines are used for corn-thrashing machines, **How used in agriculture.** for cutting and bruising cattle-food, for the haulage of steam-ploughs, for the raising of water for irrigation, and for the ginning of cotton. By contractors, **By contractors.** they are used for lifting, pumping, sawing, pile-driving, and mortar-mixing; by miners, for winding, pumping, and ore-crushing; and for all sorts of purposes and places where engines are wanted for only temporary or experimental service. There are districts in some countries, where the need for such engines is greater than in England, and the engines in use are proportionately more numerous. **In corn-growing countries.** To refer to Europe alone, portable engines of English manufacture, may be counted by hundreds,

driving thrashing-machines in the large corn-growing districts of Russia, Turkey, or Hungary; while in Egypt, for the low lands irrigated by the Nile, amidst the various machinery for raising water, portable engines attached to centrifugal-pumps are the most frequent of all. The improvements, which successive years have produced and which are now combined in a modern high-class portable engine, may be enumerated as follows:—

For irrigating.

See CENTRIFUGAL-PUMPS, *page* 208.

Usual steam pressure.

Up till the year 1865, a steam pressure of from 40 to 45 lbs. per square inch was usual, and in the competitive trials established by the Royal Agricultural Society of England, the maximum was restricted to 45 lbs. per inch; but the advantages of using steam expansively having become manifest to engineers, higher pressures were allowed, and it may now be taken as an axiom agreed to by engineers, although not yet understood by all users, that a pressure of from 60 to 80 lbs. is best suited to the economical development of the portable engine. This method of using high-pressure steam, which may be considered the most important of all the improvements, demanded suitable boilers. By innumerable experiments, carefully recorded, the proper proportions of such parts as fire-box, grate-surface, tube-surface, have been arrived at; and in order to produce a sufficient supply of high-pressure steam from a boiler of moderate size, the combustion is stimulated by the discharge of the exhaust-steam into the chimney in the manner usual in locomotives, and a separate steam-jet is generally provided for stimulating the draught before starting. Waste of heat is prevented as far as possible by covering the boiler with felt, on which are placed a lagging of wood and an outer covering of sheet-iron; and by making the cylinders with steam-jackets as already described. Superheating of the steam beyond this has not proved successful in portable engines. The feed-water is heated nearly to a boiling point by the exhaust steam, and heat is thus returned to the boiler which would otherwise be wasted. By well-arranged bearing-surfaces, balanced parts, and careful workmanship, the friction of the engine has been reduced to a minimum, and its durability increased.

High pressure.

See page 169.

Improved boilers.

Combustion stimulated.

See page 165.

Waste heat prevented.

See page 171.

Friction reduced.

Consumption of fuel.

See also page 162.

In the early trials before the year 1850, the consumption of coal, even in the best portable engines then made, was from 10 to 15 lbs. per effective horse-power per hour; but by means of the improvements enumerated above, the consumption has been reduced to from 3 to 6 lbs., and the effective force brought up to 3 or 4 times the nominal horse-power, according to the pressure of steam and speed of the engine. As a consumption so low as 3 lbs. has been only arrived at in competitive

trials by skilled engineers and with carefully-selected coal, it may be fairly reckoned that a consumption of from 4 to 6 lbs. will be necessary under ordinary circumstances. If the coal be of inferior quality, or if the combustion be forced too much, the consumption will be greater. The actual power given out by the engine as measured by a dynamometer or a friction-brake, and not the gross or indicated horse-power, is that which has been adopted for comparison; and this must be taken into account when comparing the service of a portable engine so measured with other engines whose "indicated" horse-power is alone ascertained. Where wood-fuel is used, a weight of about three times that of coal may be reckoned as an average consumption. For burning wood, the furnace-door and fire-box are made larger than for coal, and a spark-catcher is attached, the alterations adding about £1 per nominal horse-power to the ordinary price. In some corn-growing countries, where coal or wood is scarce, the straw from the thrashing-machine is utilized as fuel by means of an ingenious self-feeding apparatus, so attached to the front of the boiler that the straw is taken into the furnace at a regular and proper rate. In this way, about one-tenth of the straw from the thrashing-machine is sufficient as fuel. Engines made in this way, cost from £2 to £4 per horse-power extra, according to the exact method and patent royalty.

Minimum amount of fuel consumed.

See COAL, *page 119.*

Effective H. P.

See page 161.

Wood fuel.

Straw fuel.

The exact repetition of similar parts which the manufacture of similar engines allows, is an advantage utilized to the utmost by the principal manufacturers of portable engines. Special machine-tools and automatic processes have been invented for doing what in other cases has been done by hand-labour, or ordinary machines; and by these improved means, three distinct results have been obtained—excellence of workmanship; interchangeability of parts (so that when any are worn out, others, kept ready, or sent from the factory to replace them, will fit exactly); reduced cost.

Methods of manufacture.

See Chap. XXIII. MACHINE-TOOLS.

Parts made interchangeable.

The prices of portable engines fluctuate like those of all other machines, according to the cost of material, briskness of trade, and other circumstances. Taking an 8-horse power engine as representing the kind most in demand, the price during the twenty years ending 1880 has ranged from £200 to £280, and the prices of other sizes in like proportion. The following are about the average prices that have prevailed :—4-horse power, £170; 6-horse power, £200; 8-horse power, £230; 10-horse power, £270; 12-horse power, £320. But these prices, though inclusive of everything

Fluctuations in prices.

Extra charges.

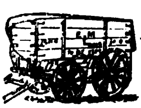
necessary to the working of the engine, are exclusive of all extras, alterations, or duplicates. Thus a feed-water heater, feed-water injector, expansion valve, link-motion reversing-gear, spare bearing-brasses and fire-bars, all add to the cost; and from £1 to £3 per nominal horse-power must be added if these are required.

Engines arranged for travelling.

For travelling on the road, or by railway, the chimney is lowered, and the engine is covered with the tarpaulin which forms part of its ordinary equipment, no other packing being required. The same plan applies for short voyages, when the engine can be taken on the deck of a steamer, except that the detachable fittings are packed in a small case.

Packed for shipment.

For long voyages, the wheels and chimney are detached, and the engine must be packed in a case, at a cost of about 3 per cent on the price of the engine. On landing, and if needed for inland transport, the wheels can be attached without unpacking the engine. The weight of portable engines packed, ranges from about 3 tons for an engine of 4-horse power, to 10 tons for one of 20-horse power; but the measurement tonnage at the usual rate of 40 cubic ft. to the ton, is about double these weights.



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See page 35.

The manufacture of portable engines forms a special trade, and English-made engines stand first both in regard to design and quality.

The purchase of portable engines.

It is expedient to purchase only from manufacturers of known reputation; even in first cost inferior engines are but little cheaper. Such engines soon deteriorate; and in case of re-sale the absence of the name of a good maker lowers their value even more than at first.

Important points enumerated.

The importance of well-proportioned parts, good material, and workmanship, so necessary in all steam-engines, is enhanced in the case of portable engines, which often have to bear very rough usage, and if defective, soon wear out. The quality of the iron and brass, the use of steel where beneficial, the accuracy of the fitting, and the proper case-hardening of the joints, are all points which determine value. The choice of a portable engine depends on the following circumstances:—

See page 179.

Power required.

1. *The Power required.* It is always economical to have ample power, as an engine and boiler are soon worn out if they are forced above their proper capacity. The pressure and piston-speed specified by the maker as best should be adhered to as far as possible.

How arrived at.

The power can be approximately calculated, if the work to be done is described; thus, if for a thrashing-machine, its kind, size, and the name of the maker should be given; if for a circular saw, its diameter, speed, and the kind of timber; if for pumping, the kind of pump the quantity of water per hour, and the height to which it is to be raised,

See Chap. XX.

2. *The Purpose for which the engine is intended.* Although the same portable engine may be applied to a variety of uses, certain minor arrangements can be made with advantage to meet special cases. Thus the diameter of the driving-wheel may be made to suit the pulley of a machine to which the power is to be applied. If for winding from a mine, reversing apparatus becomes necessary. The relative position of the engine and machine to be driven must be considered so far as it will determine whether the engine is to be right or left handed. Unless otherwise specified, the fly-wheel which serves also as the driving pulley, is generally on the left side of the boiler looking from the firing end. The engines can be constructed either way, and some makers arrange the crank-shaft so that the fly-wheel can be fixed on either side at will. **The purpose.** **Engine may be modified to suit.**

3. *The Climate and locality.* The choice of iron or wood for the wheels, and certain other minor points, can be modified to suit extremes of climate. If the engine is required in a country where repairs are difficult, certain spare or duplicate parts should be provided. **Climate and locality.** *See also page 42.*

4. *The kind of Fuel to be used.* Unless otherwise specified, the furnaces are made of the form and dimensions suitable for coal of average English quality. But almost every kind of fuel can be used —wood, turf, peat, dung, straw, or refuse cane, and if the kind of fuel be known, the furnace and boiler can be made accordingly. **The kinds of fuel.** *See* COAL, *pages 120–6.*

5. *The mode of Draught.* Shafts on poles for a pair of horses or oxen are supplied with the engine, and if above 7-horse power, double shafts if preferred. The nature of the attachment preferred, and whether for horses or oxen, should be stated by the purchaser. **Mode of draught.**

The advantages afforded by portable engines lead sometimes to their misapplication. The two distinguishing features in a portable engine, and to which it owes its value, are its self-contained completeness; and as a result of this, the facility with which it can be moved from place to place. But though this second quality, the portability, is that for which these engines were designed, and is that which really justifies their use, they are in foreign countries often chosen where no portability is needed, and because only of their completeness and readiness. In many of such latter cases, it is a mistake to use portable engines made in the ordinary form. It is doubtless a temptation to any one who requires steam-power, and especially where the purchaser or user is not an engineer, to procure an engine ready for use, which requires no foundation, house, or buildings, and not even an engineer to set it **Portable engines often misapplied.** **Portability not required.**

Fixed engines preferable.

See page 41.

to work: and where the engine is intended for a merely temporary purpose, these advantages are real; but for the purposes of a permanent stationary engine they are delusive, and in the end involve considerable unnecessary expense.

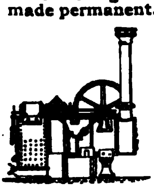
Boilers of portable engines wear out sooner than engine.

A portable engine resembles a locomotive in its multitubular boiler, and, as already explained, these boilers wear out very fast, as compared with simpler kinds. The fact that steam can be generated quickly, and that a comparatively small boiler can produce a great deal of steam, is not generally of primary importance in a fixed engine, except where mere space is very valuable or buildings expensive. A horizontal engine has, under ordinary circumstances, a much longer life than a multitubular boiler; but where it is affixed to the boiler, as in a portable engine, its life ends with it. Moreover an engine fixed to a boiler—however careful the workmanship—is not on a sufficiently solid foundation; its parts sooner become loose and irregular than in a properly fixed engine, and moreover, they shake the boiler, and hasten its destruction. These facts are so obvious, that no engineer would propose to so construct an engine and boiler, except to satisfy the exigency of portability, or to render it self-contained. The difficulties of erecting an engine in its place, of setting a detached boiler, and of connecting the pipes, are often over-estimated, for if proper instructions be supplied by the manufacturer of the engine, the purchaser, with the assistance of an intelligent blacksmith and mason, can effectually set such an engine going. To meet these objections, various forms and degrees of compromise between fixed and portable engines have been devised. The first is that of substituting rigid iron supports for the wheels of an ordinary portable engine. These supports allow the engine to work more steadily than if on wheels, and at the same time the whole machine remains self-contained and complete. It can be carried whole by ship, and to its destination, and can be removed if the necessity arises. A level and firm base should be provided for this class of engine. In French *locomobiles* it is customary to fix the working parts of the engine on one bed-plate bolted upon the boiler, so as to save the latter from strain during working. But the desired end is not entirely gained, and the engines, being less simple and accessible than those made according to the English method, have not been adopted elsewhere. In England another plan is that of placing the engine below the boiler, and on the same iron bed-plate with it on a base of masonry or timber. By this means the advantage is obtained of having the engine on a solid

Engine shakes loose.

Fixing of engines.

Portable engines made permanent.



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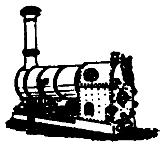
French engines.

Complete bed-plate on boiler.

Engine fixed below boiler.



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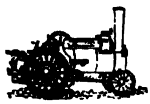
base, independent of the boiler, so that the latter can be removed or replaced; the machine, at the same time, remaining complete and self-contained. There is the same disadvantage in this plan, as in a locomotive, that the parts are not easily accessible, and that leakage from the boiler, and dust from the furnace, damage the engine; although if the boiler be well made, there need not, with proper attention, be any leakage. Engines of this class, or of the one described above, are useful in confined spaces, such as mines or small factories.

Engine separate from boiler.

The next step is to separate entirely the engine from the boiler, while retaining the latter in its ordinary locomotive shape. This is in effect a horizontal engine with separate multitubular boiler, as already described, and need no longer be discussed under the head of portable engines.

Traction-engines.



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Road engines.

Agricultural engines.

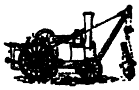
Traction-Engines, as a combination of locomotive and portable engines, need a separate description. These engines are of different kinds, the main distinction being between those where traction of heavy loads is the primary object, and known in England as Road locomotives, and those in which power to be given to another machine is the chief consideration, and the moving from place to place with the machine behind it is subsidiary. The latter kind are generally known as Agricultural locomotives. The first kind is also useful to the agriculturist in connection with certain forms of steam-ploughing, to contractors or others for hauling wagons, or to an army in the field for drawing heavy guns; the second is used for drawing thrashing and other machines (to which when they are at work it gives power) from one farm to another. Great improvements have been made in traction-engines, and there is no doubt that in the future, when the legislative restrictions (1880) to the use of steam-engines on the high roads are removed, they will be utilised much more than hitherto. The wheels are arranged with broad tires, which consolidate rather than cut up a road, and the earlier plan of equipping the wheels with rails, which were laid automatically, has been abandoned, as it was complicated and troublesome; and although difficulties often arise in passing over soft ground, they can be overcome, as in case of need, planks laid temporarily as a road will suffice. Traction-engines, in the form of boiler, and in having the engine fixed to the boiler, resemble portable engines, but are much more expensive. Traction-engines for use as road-locomotives are made generally from 4 to 12 horse-power; and for hauling steam-

Broad-tire wheels.

On soft ground.

Power and price of engines.

ploughs from 10 to 20 horse-power; the prices ranging from about £400 for an engine of 4-horse power, to £700 for 12-horse power, and about £1,000, for 20-horse power. The smaller engines are sometimes fitted as cranes, a projecting jib being attached to the front of the boiler. By this means the engine can lift heavy loads into the wagons, as well as haul the load. This crane arrangement adds about 10 per cent. to the cost of the engine. The following



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Choice of engine.

particulars are necessary to a proper choice of a traction-engine: (1) The purpose for which it is required and the weight of load to be hauled; (2) the quality and gradients of the road; (3) the kind of fuel to be used; (4) the climate; (5) if for export, the facilities for shipment and landing. It may be taken as an approximate

Weight of engine.

guide, that a traction-engine weighs about one ton per nominal horse-power, and that where the gradients do not exceed 5 per cent.

Haulage power. *See* LOCOMOTIVES.

it will draw on a good road twice its own weight, or three times its weight on a level; but much depends on the condition of the road.

Wagons.

Four-wheel wagons to carry four tons, fitted with brakes of a kind suitable for haulage by a traction-engine, cost about £70, and for six tons about £80. If only the wheels and other ironwork are required, the cost is about one-third less.

Road-rollers.

The steam *Road-Roller* is another ingenious adaptation of the road locomotive, and is successfully used in London and other large cities for consolidating newly-laid macadam. These engines are made to roll a width of from 6 to 7½ ft., with rollers generally about 5 ft.

Weight and price.

diameter: the total weight is from 10 to 20 tons, and the cost from £500 to £800 each.

Small engines bought ready made.

It may be stated as a general rule in the purchase of steam-engines, that those of less than 20-horse power may be selected with advantage from the stock of a manufacturer or dealer, and that the cheapness and convenience which such a course allows outweigh the

See page 174.

minor objections to accepting a fixed type and a ready-made machine. For more than 20-horse power it is generally desirable to have an

Existing patterns utilised.

engine made expressly, although the existing patterns of manufacturers may be utilised as far as possible. But in cases where less than 10-horse power is required, the earlier question has to be considered,

Other motors preferred to steam.

whether it is expedient to adopt a steam-engine at all, and whether some other kind of motor should not be preferred. The expenses and inconveniences which attend the use of a steam-engine bear heavily on those of small power. The skilled attendance required,

the risk and inconvenience of fire and smoke, the difficulty of examining and repairing small boilers, the loss of time between the lighting of the fire and the setting to work, have led to a growing opinion among engineers that steam-engines are not the best suited for small industries; although for engines above 10-horse power, these inconveniences have not, in the absence of alternative methods, proved sufficient to outweigh the advantages gained. For small engines these drawbacks were for a long time accepted as unavoidable, and they often prohibited the use of steam altogether. There are cases, however, where the drawbacks to the use of small engines are lessened by the circumstances attending them. The absence of a boiler is an instance; such a case occurring often in factories and other places, where small engines are used for working machine-tools, and where steam is furnished from a large boiler situated in a safe and convenient place for other purposes. The question then generally resolves itself into one of power-transmission, and the small engine is used because it is judged more convenient to bring power by steam in pipes from a boiler not too distant, than by shafting from a large engine; or because it is preferable to have a small engine available for a single or isolated machine instead of keeping a large engine at work for the purpose; or where, as in the case of a donkey-engine for feeding the boiler of a large engine, not only no separate boiler, but no additional engine-driver is needed; or, as at a steam crane the compactness which a small engine allows may be unobtainable by any other means, and the crane attendant manages the engine also. But in places where boilers and fires are inconvenient, as in crowded cities, or where the expenses of attendance bear too high a proportion to the advantages obtained, other means are available and have become widely adopted. For although steam has proved the cheapest means of changing fuel-force into mechanical power, and the one which affords the widest scope for general application, yet other methods may be preferable where the cost of fuel is not a point of the first importance; and if gas-engines maintain the position they have already (1880) attained, even the question of fuel will for them appear more favourable.

Disadvantages of small engines.

Favourable cases.

Small engines with steam from large boilers.

See page 75.

As donkey-engines.

See page 208.

Boilers often inconvenient.

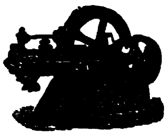
See page 73.

Gas-engines, hot-air engines, and water-engines, are the kinds which have hitherto been successfully used. Electric engines can only be used as original motors at an expense which is prohibitory on any but the smallest scale; and such engines may be considered only as a means, available in peculiar circumstances, of transmuting power for transmission to a distance.

Substitutes for small engines.

See ELECTRIC ENGINES, *p. 95.*

Gas-engines.
See also page 72.



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See page 162.
Waste of fuel in boilers avoided with gas.

Intermittent force utilized.

Improved gas-engines.

Do not need constant attention.

Used as auxiliary to steam.
See page 72.

Gas-Engines utilise heat-force in a manner quite different from that of a steam-engine—combustion, explosion, and expansion being combined in a peculiar way. If judged by expenditure of fuel, gas-engines do not differ very much from steam-engines of small power, for it is seldom that steam-engines of from 1 to 6 horse-power consume less than 10 lbs. of coal per indicated horse-power per hour. A gas-engine as made in 1880 consumes from 20 to 25 cubic feet of gas per indicated horse-power per hour, which at 4s. per 1,000 feet, amounts to about 1d., and is the equivalent of about 10 lbs. of coal at about 25s. per ton. But if, in a steam-engine, the fuel needed to raise steam from cold water when the fire is first lighted be taken account of, as well as that consumed during intervals when the engine is idle, the average consumption will, of course, be greater than that measured only when the engine is working, and, where the service is intermittent, will perhaps be twice as much; while in a gas-engine no such unprofitable expenditure is incurred, as the engine begins to work directly the gas is lit, and stops working immediately the gas is extinguished. As in a gas-engine there is not the same continuous pressure on the piston as there is in a steam-engine, the fly-wheel serves even more than in the latter to equalise the speed, and by its means, and by the effective governor which is used, the consumption of gas can be made to accord with the work done; the combustion or explosion of the gas occurring with a greater or less frequency, as power is required, whilst the fly-wheel stores up the energy thus given at intervals. The percussive action on the piston, and the effect of the gas on the slide-valve, have rendered these the most vulnerable parts of the machine, and those which have most frequently needed renewals, but the expense and trouble from these causes have been greatly reduced in the improved gas-engines since 1875. Gas-engines do not need such continuous and careful attention as the use of a steam-boiler involves, as there is neither fire to be fed nor water-level to be maintained, and therefore they are useful in private houses, or in printing factories, laundries, or in warehouses for cranes or hoists, and for the latter purpose may usefully pump water for a hydraulic lift. In city workshops, warehouses, or crowded buildings, a gas-engine has the great advantage of freedom from that risk of fire which the use of the steam-engine involves; and the cost of insurance is not increased by their use in such buildings. Gas-engines are often useful as auxiliaries to large steam-engines, either to supply the boiler with water or to drive one or more machines

when but little power is needed. They are also used with advantage for pumping up hydraulic accumulators, for opening dock gates or bridges, or wherever the service is too small or intermittent for the economical use of a steam-engine. The possible use of gas-engines for giving power to dynamo-electric machines has been already referred to. It is questionable if it would be expedient to construct gas-making apparatus merely for the use of a single gas-engine; but it might be expedient for numerous engines or where illuminating gas was also required.

See pages 72 and 95.

Gas made expressly for engines. *See* GAS WORKS, *Part I.*

Gas-engines are made of various sizes, from one-fifth horse-power to 10-horse power, the price ranging from £50 to £350, the smallest size occupying a space of about 6 ft. by 2 ft. 6 in. An engine of 1-horse power occupies about the same space, and costs about £100; one of 4-horse power costs about £180, and one of 8-horse power £250. Only very special circumstances would have (1880) justified hitherto the use of gas-engines for higher powers; but as improvements are being effected, which reduce the consumption of gas, and render more durable the parts exposed to the action of the gas, the limit of size and power, within which such engines are now so useful, will be extended.

Usual sizes and prices of gas-engines.

Larger powers probable.

Somewhat the same conveniences as those afforded by the gas-engine may—in places where there are no gas-works—be obtainable for small powers by *Hot-air engines* in which the expansive force of compressed air is increased by heating it. The ordinary air-engine is not an original motor, but one supplied (if need be, from a distance of some miles) by a separate air-compressor, and the air is applied, very much in the same way as steam, to propel, by its expansive power, a piston working in a cylinder; and sometimes the force is increased by heating the air. But the air-engines used as substitutes for small steam-engines are complete and self-contained machines, in which a large proportion of the gross power is spent in compressing the air which is then heated; and it is only the extra force due to the heating—less of course that consumed in friction—that is utilised profitably. In the simplest kind of hot air-engine there are two cylinders, one in which the air is compressed, and the other in which it expands and does its work. At the bottom of the working cylinder is a small furnace for heating the air, and this can be so arranged as to burn with only occasional attention. These engines are most suitable for powers of from ½-horse power, to 2-horse power, and can be con-

Hot-air engines.

Compressed air. *See page 86.*

Self-contained engines.

Mode of working.

Usual limit of power.

veniently used in private houses or small workshops, the smoke being taken either through a sheet-iron chimney, 8 to 12 ft. high, or into an ordinary house chimney or flue. For organ-bellows and other purposes, where but small power is required, the heat may be supplied from gas-burners. An air-engine of ¼-horse power occupies about

Space occupied. 5 square ft. of ground space, stands 4½ ft. high, with a fly-wheel 2 ft.

Prices. diameter, and costs about £40, while a 2-horse power engine—and they are seldom made larger—costs about £140. The consumption of fuel is more than in a gas-engine, but this may be, under certain circumstances, of small consequence if compared with the advantages afforded. These engines are very useful for either continuous

Engines useful for pumping. or intermittent pumping, where the quantity of water required is not enough to justify the cost of a steam-engine and engine-driver. For instance, at a roadside railway station the water-supply for

See Chap. XXI. locomotives may be thus maintained, and the occasional attention of a labourer or porter may suffice to keep engine and pump going.

Water-engines. *See also page 78.*

Water-Engines are made of various kinds, but in the mode of applying them may be divided into three categories, first :—those which

Are of three kinds. are available as original motors for utilizing directly the natural gravity force of a waterfall or rapid; secondly, those which utilize the gravity force of water which has been pumped up by a steam-engine, waterwheel, windmill, or other original motor to an elevated reservoir; and thirdly, those which derive an artificially-concentrated force from an accumulator-load kept continually lifted by a pumping-engine. The water-engines in the second and third categories may be, and

See Chap. XVII. generally are, worked at a considerable distance from the original motor, and are therefore adjuncts to a system of power-transmission, but it is those in the second category alone which are generally available as substitutes for small steam-engines, although it is not un-

See page 82. likely that the accumulator system, which is so widely used for cranes, may be extended to, and rendered available for small motors also.

Transmuted force. The transmutation of force derived from some original motor involves loss or expense, and therefore needs justification, which in the case of water-power is found in the convenience for transmitting to a distance and distributing in various directions, in quantities however small, power derived from a large central motor. But these advantages, which render water-power convenient and economical for small

Costly for large powers. engines, are not sufficient to warrant its use for large powers, where the cost of pressure-water would bear so high a proportion to the

total expenses as to render the direct use of a steam-engine preferable. The selling price of water in English towns varies considerably, but not according to the pressure, and therefore water which may be cheapest according to the ordinary measure by quantity, may be dearest for power purposes.

In a town-supply, although payment for water for domestic consumption is, for convenience, assessed by a rate according to the value of the houses, large consumers are supplied by measure of quantity, and prices vary from 4d. to 2s. per 1,000 gallons. But, as high-pressure water can seldom be obtained at the lower price, and as the higher price prohibits the use of engines, the cost according to force has a narrower range, and if water from the public mains were bought for use in water-engines, probably 6d. to 2s. per horse-power per hour would, with few exceptions, include the highest and lowest prices charged in England. These rates practically forbid the use of water motors, except for direct acting hoists or other intermittent purposes where the consumption is small. The rates are determined not so much by the expense of pumping up the water, as by the fact that the corporations who own or control the supply seldom favour the use of water as power, and are unwilling to sell it at rates or prices so measured. In England, gas-engines, though dearer to purchase, can in the majority of cases be much more cheaply worked than water-engines; and when the latter are preferred, it is generally for one or more of the following reasons; namely, where water may happen to be cheap and coal-gas dear; or because the water has a value after it has done its work in the engine, as in a paper-mill, dye-house, or brewery; or because a gas-engine is objected to on the score of nuisance, or as requiring more attention than a water-engine; or because the greater space occupied by the gas-engine is of consequence; or because of the small cost of a water-engine.

See page 80; also WATER WORKS, *Part I.*

Cost per H. P.

Greater than fuel force. *See page 72.*

And dearer than gas fuel. *See page 192.*

Favourable cases for water-engines.

Where there is an abundant supply of water, and a site for an elevated reservoir, a municipal body, or others who have control, might often, with great advantage to the community, promote local manufactures, especially those of small extent, by selling the water as power, and encouraging its use by moderate tariffs. Indeed, when concessions or monopolies for the supply of water are granted, stipulations to this effect might often be inserted with advantage. On the other hand, where seasons of drought or restricted supply occur, such stipulations might need so many qualifications as to render the use of water-engines altogether inexpedient.

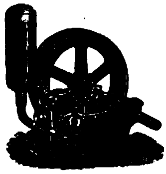
Use of water as power extended.

See page 78.

See Part I., pages 34 and 171.

See page 83.

Different kinds of water engines. Small water-engines are of various kinds, but, omitting water-wheels, there are three principal types—first, engines having a fixed cylinder—almost always horizontal—with a moving piston, like a steam-engine; second, oscillating cylinders, also with a moving piston; and third, rotary engines, sometimes with a revolving piston, but more frequently in the form of a turbine. The first kind are used for pumping, for **For slow or for quick motion.** hoists and cranes where a long stroke and slow motion are required, the second and third for small motors of considerable speed for giving a rotary motion. **Advantages of water-engines.** *See page 78.* Water-engines of these kinds are small and compact, with few working parts, and have the advantage that they can be easily started and stopped instantaneously, and involve neither heat, fire, nor smoke. The value of a water-engine increases rapidly with the degree of pressure available; for not only does the power which an engine of certain size and occupying a certain space affords increase, but the price of water, if measured by units of force, is almost always cheapest when of high pressure. As an almost invariable rule, it is inexpedient to use a water-engine when there is less than 60 ft. head of water (26 lbs. per sq. in.) and the advantages increase up to 500 ft.; the exception being when there is a very abundant supply which can be utilised by a turbine. The pressure in the public water-mains of a town seldom exceeds 300 ft., and is generally less. Care is necessary not to reckon too certainly on the nominal pressure of a town-supply, as there are various causes—such as the abstraction of water from the mains for other purposes, or the obstruction caused by bends, valves, and meters in the communicating pipes—which diminish the pressure in actual working; and the difficulties which arise are sometimes increased or maintained by the action of the corporate body who sell the water.



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High pressure cheapest.

Minimum pressure.

Nominal pressure seldom obtained.

See page 214. FIRE EXTINCTION.

Prices of water-engines. The cost of water-engines may be conveniently stated not according to their power, but according to that capacity for power which the actual pressure available must determine. For instance, an engine with a pair of oscillating cylinders 4 in. diameter with a stroke of 8 in. and occupying a space of 2 ft. by 1 ft. 6 in. by 2 ft. high, would with a 100 ft. head of water give out 2 indicated horse-power, while the same engine would be strong enough to give out 6-horse power with a 300 ft. head of water. Smaller engines of this kind, expressing from ¼ to 1 horse-power, cost from £20 to £40.

[*See also* PURCHASE FOR EXPORT: THE ESTABLISHMENT OF FACTORIES: TRANSMISSION OF POWER: PUMPING ENGINES: PIPES.]

CHAPTER XX.

PUMPING-ENGINES. FIRE-ENGINES. TANKS. PIPES. TUBES.

ENGINES for pumping need a classification of their own, apart from those for general uses described in the preceding chapter; but though all applied to this one general purpose of raising water, the forms, systems, and methods employed to meet the various difficulties which occur are of the most diverse kinds. Too often, however, the inventors or manufacturers of pumps which may be suitable under certain conditions ignore or do not sufficiently describe the circumstances under which their machines would be unsuitable; and unnecessary expense or complete failure generally attends the use of pumps so misapplied. It is not intended here to describe all kinds of pumps, nor to compare their merits, but only to draw attention to the leading points by which a choice should be determined.

Pumping engines are of various kinds.

Often misapplied.

The incidents already described as affecting the choice of a steam-engine, are most of them applicable to steam pumping-engines also, and need not again be enumerated; but there are obviously others which apply particularly to pumping. The quantity of water to be raised in a given time being known, and the height to be lifted, some or all of the following circumstances have then to be considered, namely—(1) The kind of force available or the reasons for and against any particular form of power, such as animal or manual force; or power derived from steam, water, or wind; or from shafting. (2) The special purpose of the pump; whether temporary or permanent; for raising large volumes of water to a small height, as for irrigation; or for raising water to a great height, as in a mine. (3) The locality or situation of the pump, which may render certain kinds of

Leading points to be considered.

Quantity, height.

Kind of force.

Purpose.

Situation.

Distance. pumps desirable or impossible. (4) The horizontal distance, the total length of the line of pipes, and the diameter of the pipes. The power required to overcome the friction of the water in the pipes depends upon these circumstances. **Secondary points:** The choice of a pump is often wholly determined by secondary questions, and the first cost and the power consumed in working may be made subordinate to the necessity for fixing the pump in a particular place, or the driving it from some existing boiler or steam-engine or running shaft.

Classification of pumps. Pumps may be classified as *Lifting-pumps*, *Forcing-pumps*, and *Pressure-pumps*, all of which have a bucket or plunger with a reciprocating motion. Outside this classification are *Centrifugal-pumps* and *Chain-pumps*. Rotary forcing-pumps are not included in any of these categories; but they are not for the present purpose of sufficient importance to need more than a passing reference. *See page 207.*

Lifting-pumps: *Lifting-pumps* have for their characteristic feature the hollow bucket through which the water, after it has been forced up by the atmosphere during the forward stroke, passes as the bucket returns. This kind of pump is that most generally known, and it is employed almost invariably for pumping from wells; though sometimes a forcing plunger is combined with a lifting bucket. *See page 199.* Commencing from the familiar hand-pump, which can be purchased for £1 and upwards, the sizes increase until the use of steam-power becomes expedient. **Variety of shape.** There is an infinite variety of shapes and methods of placing these pumps and of applying the power, and hundreds of engravings would hardly suffice to show the various patterns made by different manufacturers. **Cost of small pumps.** For pumps worked by manual force, the cost will range from £10 for a pump capable of raising with one man 2 gallons 40 ft. high per minute, to £25 for one capable of raising 7 gallons 50 ft. high with two men. Beyond these capacities steam or other artificial power becomes necessary, and the cost depends on various circumstances other than the quantity of water and the height. **Limit of lift by vacuum.** As these lifting-pumps are so frequently used for moderate depths, and are generally in such cases fixed on the ground-level, it is necessary to remember that, as the vacuum formed by the pump is able to draw only from a depth of about 25 ft., the effective part of the pump (the working barrel) must be placed below the ground and within 25 ft. of the water when a greater lift is required. **Rising main.** If, besides lifting the water to the ordinary level of a discharge spout or pipe on the working barrel, it is desired to raise the water still higher through a rising main to the ground-level or above it, then

the joints and other parts of the pump must be made sufficiently strong and water-tight to resist the pressure of the column of water. Suction-pumps of this class are not suitable for raising hot water, as the steam prevents the formation of a vacuum; and, therefore, for hot water it is usual to employ a force-pump placed below the level of the water to be raised.

Vacuum prevented by hot water.

Force-pumps have a solid bucket, or plunger, or piston, which works in a barrel, box, or chamber, furnished with inlet and outlet valves; the water flowing through the inlet valve into the chamber as the retreating plunger leaves a vacuum behind it, and being forced through the outlet valve into the rising main by the plunger as it returns. But although this general principle is common to all force-pumps, which may be, and are, used for lifts up to 2,000 ft., the pumps vary in detail as much or more than do lifting-pumps.

Force pumps.

Vary in kind.

A plunger passing through a stuffing-box is generally used for single-acting pumps; but for double-acting pumps, a solid piston or bucket with a piston-rod is necessary, so that the alternate operations of suction and pressure may be performed as well above the piston as below it. "Bucket and plunger" pumps are those in which a forcing plunger is fixed above the bucket on the same rod, so that while there is only a single-acting suction as the bucket ascends, there is a double forcing or delivery, as the plunger is arranged so as to force both at the forward and return stroke. The advantage so obtained is carried further in some cases by the use of two engines, each with two discharges, so that by thus having four discharges the oscillations or shocks incident to single-acting pumps are avoided. The continuous flow of water which is afforded by double-action pumps is sometimes obtained by a series of single-acting pumps working side by side from one shaft, the most uniform being the "three-throw pump."

Solid pistons.

Bucket and plunger pumps.

Three-throw pump.

Manual power is seldom used for force-pumps, the great majority being worked by steam through the medium of cranks or eccentrics from a revolving shaft. For pumps of considerable size, requiring more than 4-horse power, a separate steam-engine is generally attached to the pump, steam being supplied either from a boiler of corresponding size, or from a larger boiler used for general purposes. Smaller pumps are worked from shafting driven by a steam-engine or other motor. The latter method is adopted, for instance, in breweries, dye-houses, and chemical works for the numerous small pumps which are required at various places, even where the principal pumping is

Manual and steam pumps.

Pumps worked by shafting.

Limit of distance. *See page 103.*

effected by a special steam-engine. While, however, it is convenient thus to utilise shafting which is already established for transmitting power to pumps of moderate size, it is seldom expedient to bring power more than 50 ft. in this way. Where possible, the pump should be brought nearer to the motive power, and where this is not possible or convenient, the alternative plan should be considered of attaching a steam-engine to the pump, and bringing steam from a distant boiler, for there is by such a plan much less loss in transmission than by shafting. It is in cases like these, where contiguous power is not obtainable, but where steam can be brought in pipes from a distance, that steam-pumps are particularly useful.

Steam pipe. *See page 73.*

See page 204.

Pumps for mines. **For town supply.** **Beam-engines.** *See page 172.*

Non-rotative pumping-engines for raising water from mines are almost invariably made as force-pumps, with solid plungers or pistons; but those for the supply of towns have often the combined bucket and plunger. The earlier pumping-engines for both these purposes were almost all made with rocking-beams of the familiar type. Resembling each other in general form and principle, beam pumping-engines may be broadly classed in two divisions, as non-rotative and rotative; a varying preference being shown for one kind over another by different engineers. In the rotative engine the beam is attached by a connecting-rod and crank to a revolving shaft, and there is a fly-wheel and continuous motion; in the non-rotative the beam has an intermittent motion, and there is no revolving shaft or fly-wheel. In both alike, the rocking-beam receives its motion at one end from the piston-rod, and at the other gives motion directly or indirectly to the pump-rods. It may be said generally, that the non-rotative engines are applied principally to deep mines, where water has to be lifted from a constant depth, the long and heavy pump-rods being attached directly to the beam which overhangs the mine shaft, the beam, when the weight of the pump-rods much exceeds that of the column of water, being partly balanced by a "bob" or counter-weight. In the rotative engine the fly-wheel equalises the motion and power under the altering pressures of steam used expansively. These engines are almost always preferred to non-rotative engines at water-works, or wherever the higher level to which the water is to be raised is above the level of the engine, and where, therefore, whatever the height and weight of the column of water, there is no great load of suspended pump-rods. There is the advantage in the rotative engine that the speed of the pump-bucket, as regulated by the fly-wheel and crank, accords with what is best suited for the

With and without fly-wheel. **Balanced beams.** **Advantages of rotative engines.**

passage of water through the valves, starting or putting the water in motion with a gradually increasing speed so that the valves open easily at the commencement of the stroke and close gently at the end. In a non-rotative engine, on the other hand, the stroke of the pump commences with a high speed, and elaborate valve arrangement and careful supervision are necessary to prevent an over-stroke of the piston, the ingenious motion of the "cataract" being substituted for the direct control which a crank affords. Moreover, if the steam for such an engine be used expansively to prevent waste of fuel, the pressure on the steam-piston, and consequently the power of the engine, which has no fly-wheel to store up and equalise its force, are not the same at all parts of the stroke, while the resistance of the column of water in the pump is constant; and this inequality is sometimes the cause of breakage where the variation is very great. There are various secondary or minor considerations which assist a choice between these two kinds, and it is only engineers specially acquainted with such matters who can decide in a particular case upon the best kind.

Allows equable working.

Non-rotative engines.

As used for pumping.

The regular and smooth working of the beam-engine is considered by many engineers to render it particularly suitable for continuous pumping for the water-supply of towns, the minimum risk of stoppage more than compensating for an increased first cost. As already stated, the extra expense of a beam-engine, as compared with a horizontal engine, lies not only in the engine itself, but in the extra expense of foundations and buildings. As an example, a beam condensing engine and boilers, for pumping 60,000 gallons of water per hour to a height of 300 feet, would cost in England from £6,000 to £7,000, and the foundations and buildings about £3,000; while a hozizontal condensing-engine of similar capacity would cost, with foundations and buildings, about one-third less. When, as is often the case, pumping-engines are erected in duplicate as a reserve against accident, the difference in cost is of course increased. The continued favour in which the beam pumping-engine has been held so long has been probably owing to the economical working which has been obtained with such engines. The high cost in Cornwall of fuel brought from a distance stimulated all inventions which economised heat; and the introduction of the Cornish boiler and improved beam-engine were keenly appreciated; while on the other hand, in the northern parts of the island, the abundance of cheap coal rendered the consumption of fuel a question of slight importance, and directed the attention of mine-owners to mere saving in first cost. Therefore,

Beam-engines for town supply.

See page 172.

Are expensive.

Example.

Allow economy of fuel.

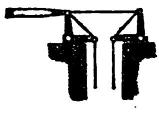
Cornish engines and boilers.

See page 164.

although beam-engines were formerly used in the north, and continue to be used there, they have not been worked so economically as in

Horizontal engines. *See page 173.*

Cornwall. The horizontal engine has, as a cheaper type, been widely adopted, and the majority of new engines in the northern counties are of this form. For pumping from deep mines by a horizontal engine on the ground-level, motion is given to the pump-rods by bell-cranks or quadrants, and in some cases, in small mines, or where the pumping is not important, the same horizontal engine both pumps and winds.



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Vertical engines.

Bull engines.

Direct-acting vertical engines are also used for pumping from mines, and are known as bull engines, the steam cylinder being placed directly over the mine shaft, so that the piston pulls directly on the pump-rods. Engines of this class will pump as much as 600 ft. in one lift, and no quadrants or bell-cranks are required. But though such engines are cheap and involve much less expenditure on buildings than other kinds of engines, they consume much fuel and are therefore only adopted where fuel is very cheap.

Difficulties in deep-mine pumping.

The principal difficulties in deep-mine pumping are in the transmitting of power from the engine on the surface to the pump far below; in the enormous weight of the column of water in the rising main; in the packing of the stuffing-boxes of the pump plungers to remain water-tight; and in the maintenance and smooth working of

Division into lifts.

valves and valve-seats under the great pressure. In deep mines it has been customary to divide the total operation into several lifts of practicable dimensions. Thus, one pump is placed at the bottom of the mine to raise the water to a certain height into a reservoir or "sump," from which another pump raises it to another reservoir, and

Reduces pressure.

so on till the surface is reached. By this means the pressure upon the pipes and valves, as determined by the height of each separate

Weight of pump-rods.

rising main, is kept within practicable limits. But the weight of pump-rods to work these pumps is very great, and in mines 1,000 ft. deep and upwards the suspended pump-rods will weigh as much as 50 tons. Among the most important improvements in connection with deep-mine pumps have been in the "clacks," valves, and valve-seats,

Valves liable to fracture.

and in the material of which they are made. The enormous load under which the valves have to open and shut subjected them to severe shocks, and, notwithstanding all precautions, pumping operations are frequently interrupted by the bursting or breaking of the valves and valve-cases. In fact the efficient working of the pump may be said to depend on the proper construction of these parts, to which accordingly, the ingenuity of engineers has been much directed.

Various forms of double and treble beat valves and equilibrium-valves have been invented from time to time, which allow large quantities of water to pass at each stroke with but slight lifting of any one valve, and the percussion consequent on the closing of the valves has been reduced to a minimum.

Equilibrium-valves.

In regard to the expenditure of force for producing certain results, the service performed by a pumping-engine is so very evident and, as compared with most of the miscellaneous duties performed by steam-engines, allows of such easy measurement, that any improvements obtained which save power become at once apparent. The number of gallons per minute, and the height lifted for a given expenditure of fuel, are the simple factors in the calculation; or if, instead of gallons, pounds of water be taken, then by the customary units of foot-pounds, the service obtained by each horse-power or by each pound of coal, can be conveniently measured. At the time when Watt commenced his improvements, the atmospheric steam-engine then used at the Cornish mines were, at their best, capable of raising 70,000 lbs. of water one foot high for each lb. of coal consumed. Not only, however, did the fuel produce a result thus small, if judged by modern standards, but the pumping was limited to a certain depth, because the engines, with a pressure only equal to that of the atmosphere against a vacuum, could not, with any convenient or practicable size of engine, produce a power to overcome more than a certain weight of water and pump-rods. Thus, mining in Cornwall was till Watt's time limited to a moderate depth, and minerals below were all inaccessible. Watt's valuable improvements, by which the effective force obtained from an engine of given dimensions was increased, also allowed a great saving in coal, for his engines proved capable of raising 200,000 lbs. of water one foot high for each pound of coal; or, if judged by the standard of horse-power, was equal to a consumption of 9½ lbs. per effective horse-power per hour. By various improvements in the arrangements of boilers and furnaces, by using steam-engines expansively, and especially by the use of compound engines, the quantity of water raised one foot high, or, as usually stated, the *duty* of the engine has been increased to about one million lbs. per lb. of coal consumed, or, to state it by the more familiar measure of horse-power, only about 2 lbs. of coal of average English quality, are consumed for each effective horse-power per hour, the exact consumption depending of course on the quality of the coal. There is no kind of purpose to which the steam-engine

Power needed for pumping.

Gallons per minute.

Horse-power.

See page 160.

Consumption of fuel.

Watt's engines.

See page 162.

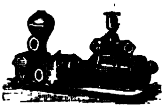
Duty of engine per lb. of coal.

See page 162.

See COAL, *page 119.*

is applied which allows such equable results as are obtained from the regular working of a large pumping-engine.

Steam-pumps.



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A valuable addition to the methods previously available for raising water has been made by the invention of direct-acting *Steam-Pumps*, of which many thousands have been sold in England and America during the ten years ending 1880. The principle of these machines is in their direct action, the pump and steam-cylinder being placed close together in a line upon one bed-plate, the piston-rod from the steam-cylinder being continued into the pump, and attached to the water-piston.

Continuous action.

The rudimentary difficulty in such a direct-acting pump is obviously the maintenance—without a fly-wheel and without the elaborate apparatus which is used in a non-rotary beam-engine—of continuous action.

Will work at any speed.

This is however so completely effected that the engine can be made to move with equal certainty at one or one hundred strokes per minute, as the amount of work may demand.

Size of steam-piston.

The proportion which the diameter of the steam-piston bears to that of the water-piston depends of course upon the height to which the water is to be lifted, *i.e.*, upon the available pressure on the one hand, and on the weight to be overcome on the other.

According to service required.

With a given pressure of steam on a piston of given area, a certain weight can be lifted, and this weight may either be a short column of great diameter or a high column of small diameter, or, in other words, a great quantity of water for a short height, or a small quantity for a great height; and the size and power of a steam-piston may be made of any reasonable proportion necessary to overcome the pressure opposed to it.

Ordinary sizes.

For the numerous purposes of pumping in factories, breweries, chemical works, and other places where the quantity of water to be raised is from 1,000 to 10,000 gallons per hour, and the height to be lifted is between 20 and 250 ft.; pumps of some size between 3 in. and 7 in. diameter, with steam-cylinders of from 3 in. to 14 in. diameter, are sufficient, the stroke ranging from 9 in. to 24 in.

Prices.

Steam-pumps of these sizes are, because of their simplicity and compactness, very cheap, and any combination of steam-cylinder and pump within the above limits can be purchased (exclusive of boilers and piping) at some price between £20 and £120.

Quantity of water.

The *quantity* of water which can be pumped in a given time depends on the size of the pump-cylinder and the number of strokes per minute; and manufacturers rate their pumps accordingly.

Height lifted.

But the *height* to which the water can

be raised depends upon the pressure in the steam-cylinder. If there were no loss in working, it is obvious that the steam-pressure would have to exactly balance the weight of the column of water. That is to say, in order to raise water 100 ft. high, a pressure of 43½ lbs. per square inch would suffice if the piston were of the same area, because a column of water 100 ft. high weighs 43½ lbs. per square inch, so that for each lb. of pressure the water would be raised about 2 ft. But as there must be loss from friction and other causes, it is usual to assume only 1½ ft. of height for each lb. of steam if the pump-piston and the steam-piston are of the same diameter, and on this basis the results which cylinders of different diameters would afford may be also calculated. As an example, a pump with a water-piston and steam-piston, both of 4 in. diameter, and an effective length or stroke of 12 in., will with 50 strokes per minute propel about 3,000 gallons per hour. With steam of 40 lbs. pressure, the water could be raised to a height of 60 ft., and with steam of 80 lbs. pressure, 120 ft.; but if a steam-cylinder and piston of 8 in. diameter (which affords an area four times that of 4 in.) were used, the same pump, if maintaining the 50 strokes per minute, would with 40 lbs. of steam, raise 3,000 gallons 240 ft. high. A pressure of from 50 to 70 lbs. per square inch would probably afford the best results; but as purchasers are not always inclined to work at such pressure, only 40 lbs. is usually assumed by the manufacturers in calculating the size of pump necessary for a certain service. For situations where a steam-boiler is not already available, and where one has to be obtained, the steam-pump can be purchased with a boiler attached to it, forming when so arranged a complete self-contained pumping-machine, the cost, however, being nearly treble that of the steam-pump alone. In factories where there is no boiler from which steam can be obtained, or lines of running shafts by which power may be given to ordinary pumps, these self-contained steam-pumps are very convenient.

Depends on steam-pressure.

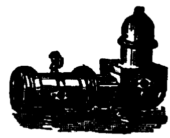
See page 76.

Proportionate area of steam and water pistons.

Results from different pressures.

Pumps complete with boilers.

Pumps of this kind are valuable chiefly for their compactness, simplicity, and cheapness; but they consume more fuel than do non-condensing engines in which high-pressure steam is used expansively and much more than well-arranged compound engines. The consumption of fuel in pumps of the sizes described above is, however, often of little consequence compared with the advantages afforded. But for pumps of larger capacity, and for raising water from deep mines, economy of fuel becomes a matter of the first consideration,



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Steam-pumps for mines.

Fitted with condensers. and to meet these cases, while still retaining the peculiar advantages of the direct-acting steam-pumps, the latter can be fitted with condensers (the exhaust-steam being discharged into the suction-pipe of the pump in a very simple manner), and the application of the compound system to these pumps promises (1880) still further to improve them; but the mode of working forbids so great an economy as is obtained in compound engines. **Large sizes of pumps.** For deep-mine pumping much larger sizes than those above described are made, pumps up to 14 in. diameter, and steam-cylinders up to 40 in. being practicable and usual, the total cost in such extreme cases ranging from £1,000 to £2,000, including boilers. These engines, when used for mines, are placed at the bottom of the shaft, and force water to the surface in one rising main. **In deep mines.** The absence of long pump-rods, of numerous valves and clacks, and the direct action of the steam-piston which, as above described, is graduated in size to meet the exigencies of the resisting pressure, allow these machines to pump from the mines even 1,000 ft. deep in one lift, the pipes and pipe connections being made proportionately strong. **Steam supply from surface.** When the pump is thus placed below ground the steam may be supplied from a boiler on or below the surface; and it is found that, if the pipe be properly protected, the condensation is not inordinate and the loss of pressure between boiler and pump, *See page 73.* after the pipes have become warmed, need not exceed ½ lb. for each 100 ft. **Advantages.** Steam-pumps, as above described, are so self-contained, that little preparation or foundation is necessary to receive them. **Occupy small space.** Not only do they occupy little space, but in a mine, the steam-pipe does not interfere with the free use of the mine shaft for other purposes, while with an ordinary mine pump, the rods and other gear require, in many cases, a separate shaft. **Useful for temporary work.** In temporary work, for instance, where a new mine has to be explored, and where, therefore, the continuance of the pumping is doubtful, the large saving in capital outlay is of great importance.

Water-engines for pumping. *See page 194.* Pumping-engines worked by water instead of steam are useful, either where water sufficient in pressure and quantity is easily and cheaply obtainable as power, or in other cases where the use of steam is inconvenient or impossible. *See page 78.* Thus the current of a river may, by the means of turbines or wheels, pump up the water to an elevated reservoir. **Useful sometimes in mines.** In mines where the water occasionally rises above the place where the pumping-engine is placed, an engine which would have to stop working if dependent on steam, could continue pumping if worked by water. A small quantity of water having great pressure

can be applied to raise a larger quantity of water to a less height, and where the pumps are submerged, can pump the mine water to an intermediate level, where steam or other ordinary pumps are available for raising it further. But while this method is thus useful under special circumstances, it would generally be a wasteful application of power where ordinary methods are available.

If steam-pumps are submerged.

Water can be applied as power under conditions the reverse of those above described, *i.e.*, a large volume of low-pressure water can be used to pump a small quantity to a great height. Self-acting *hydraulic-rams*, as they are called, placed near a stream or waterfall, can be applied to force water to a height ten times that of the fall. Small machines of this sort for forcing from 300 to 5,000 gallons per hour cost from £10 to £40, exclusive of piping.

Hydraulic rams.

Various other kinds of pumps not referred to here have been introduced to meet peculiar difficulties of locality or purpose; but many of these new inventions have little to recommend them but the novelty and ingenuity of their design. It will generally be found that the conveniences afforded by exceptional contrivances for pumping on a small scale are neutralised by practical difficulties and great consumption of fuel when it is attempted to apply such pumps on a large scale. *Rotary* force-pumps have been designed in various ways, and have been more successful than steam-engines of that form, because there is not the difficulty connected with a rotating steam-piston. Indeed, most of the rotary engines which have been designed will serve as pumps when driven by some other motor, and many of such engines have found their only real use as pumps. Or if two such machines be coupled together to one shaft, one will serve as motor to drive the other as pump. Small water-engines are often applied in this way, but rotary pumps, as hitherto (1880) made, are not likely to supersede pumps with the more usual reciprocating movement.

New inventions for pumping.

Seldom successful.

Rotary pumps.

Coupled with rotary engine. *See page 175.*

Pressure-pumps are those which have to overcome some force other than that of the rising main or column of water, and the two principal applications of these pumps are for feeding steam-boilers and working hydraulic presses. For supplying steam-boilers in the earlier times, when low-pressure steam of from 7 lbs. to 15 lbs. per inch was used, no feed-pumps were necessary, as a tank was easily placed at a height above the boiler sufficient to give a head or weight of water which would enter the boiler against the steam-pressure. Now, however, the pressure to be overcome ranges from 30 lbs. per inch

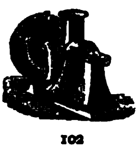
Pressure-pumps.

For feeding boilers.

for feeding the boiler of a low-pressure engine to 160 lbs. per inch in a locomotive. Almost all engines are provided with a feed-pump worked by some part of the moving gear, but sometimes the ordinary feed-pump is supplemented or superseded by a *donkey-pump*, or by a steam-injector. This name, "donkey-pump," has been given probably only because of the secondary or subsidiary service rendered, as, except in size, there is nothing peculiar in the principle of such machines. The pumps are made in a variety of shapes and forms, as vertical and horizontal rotating-engines; and the direct-acting non-rotative steam-pump just described, is also used for the purpose; the one feature aimed at in them all being compactness of size and shape; for while, even in an ordinary engine-room, space is often limited, in the engine-room of a steam-ship, or on the side frame of a locomotive, space is obviously confined. A donkey-pump for feeding the boiler of a 10-horse-power engine will cost according to its kind from £20 to £30, the cost increasing with size, so that for the boilers of a 100-horse-power engine from £50 to £100 is required. A donkey-pump allows water to be supplied to a boiler without working the main engine, which, especially in the case of a steam-ship or locomotive, is often convenient. Donkey-pumps of moderate size can be worked by manual power for the washing of boilers, or to fill or feed them before steam has been raised sufficiently high to perform the service in the ordinary way.

Donkey-pumps. Of various shapes. Small and compact. Prices. Manual donkey-pumps.

Centrifugal-pumps.



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The *Centrifugal-pump* differs from any of those described in the preceding pages, for in the ordinary sense it is neither a suction-pump nor a force-pump. In its form and manner of working it resembles rather an air-fan, having, like it, a disc with radiating blades revolving at a high speed within a case. This case must first be charged with water, which will then be displaced by the revolving disc; a partial vacuum being thus produced in the case, the water follows by the pressure of the atmosphere to be once more displaced and thus passed into the delivery-pipe. At their first introduction, about the year 1850, the blades were made straight, but a closer investigation into the theory by which these pumps work, aided by practical experience in their operation, has resulted in the adoption of blades bent exactly to the most effective curve. Other improvements have been made in the shape and arrangement of the parts, which in modern centrifugal-pumps are so contrived as to allow of easy access to the interior of the pump, and the removal or addition of pipes without

Improvements in shape.

disturbing the whole machine. The suction and delivery-pipes are usually made vertical, and the inlet and outlet on the pump are arranged accordingly in the absence of stipulations to the contrary. But the pump can be made for horizontal suction or delivery-pipes, if desired. The manufacture of centrifugal-pumps is in few hands, for while other pumps are widely understood, and can be made at any engineering factory, the proper design of a centrifugal-pump demands an exact application of scientific principles which can be arrived at only by much study and careful experiment. Those who have succeeded in the manufacture of centrifugal-pumps have a corresponding absence of competition; and as they make large numbers of these pumps exactly alike, special tools can be provided and other economies in manufacture practised, which are only possible where repetition is assured; and such methods not only improve the workmanship but reduce the cost. As the pumps revolve at a high speed, it is of great importance that the moving parts be exactly balanced, that the spindles be hard and strong, and the bearings long and well fitted. These conditions are satisfied and strength is combined with lightness by the free use of steel and gun-metal.

Position of pipes.

Manufacture requires special knowledge.

Trade is in few hands.

Importance of good fitting.

Centrifugal-pumps are occasionally used for lifts as high as 100 ft.; the manufacturers recommend them only for lifts up to 80 ft., they seldom compare favourably with other kinds for lifts over 30 ft., and the vast majority of centrifugal-pumps are used for lifts not exceeding 20 ft. The effective results obtained from centrifugal pumps for a given expenditure of power or fuel are not generally as great as in some other machines—for instance, as in a deep-mine pumping-engine—but the improvements in design and manufacture have continued to increase, and well-made pumps now give out an effective service of about 70 per cent. of the powers applied to drive them. It is immaterial where the pump is placed, whether near the water or at a maximum distance of 27 ft. above it, so long as all the joints are perfectly tight and no air is admitted.

Limits of lifting.

Consume more power than other pumps.

Height of suction.

A centrifugal-pump of a certain diameter, driven at a constant speed, will raise a certain quantity of water to any height within its capacity, but the power necessary to maintain the speed and the same quantity of water obviously must vary with the height lifted. This may be illustrated by a few examples. A small pump, with a 6-in delivery-pipe, costing, inclusive of piping, about £30, will raise 500 gallons of water per minute to any height up to 70 ft., and will require about ⅕-horse power for each foot of lift. A

Examples of capacity and price.

pump with a 6-in. delivery-pipe, costing, exclusive of piping, about £120, will lift 3,000 gallons per minute, requiring 1-horse power for each foot of lift.

Driven by belt from portable engine. *See page 183.*

Pumps of the above sizes are generally driven by a belt from the fly-wheel or pulley of a steam-engine. Portable engines are often used, and in some cases—as for irrigation—engines and pumps are permanently arranged together for this purpose only. Where centrifugal-pumps are employed for temporary service only, and have to be moved from place to place, they are frequently attached to a light carriage on two or four wheels.

How best applied.

Centrifugal-pumps find their best application in those cases where large quantities of water have to be lifted a moderate height in a short time, such as in the irrigation or drainage of land, emptying of docks, ships, or caissoons; and for sheep washing. In these cases the great facilities which these pumps afford by their simplicity, compactness, and cheap first cost, compensate for any saving in fuel which more elaborate, costly, and permanent pumping-machinery might possibly afford. Many large pumps are made for these special purposes, especially for the drainage of low-lying land; the largest proportion range in size from those with pipes 18 in. diameter, costing about £200, and capable of raising 5,000 gallons per minute, requiring about 2-horse power per foot of lift, to those with pipes 48 in. diameter, costing about £1,000, and capable of raising 30,000 gallons per minute, requiring about 12-horse power per foot of lift. Large pumps of this kind are often attached direct to a steam-engine, whose crank-shaft forms the pump-spindle.

For drainage.

Cost of large pumps.

Chain-pumps.

Mode of working.

Chain-pumps consist of a tube or barrel, round or rectangular in section, and made of cast or wrought iron, and an endless band or chain, generally made of iron links, working continuously up the tube and passing round pulleys at the top and bottom. Upon the band are flaps or buckets which lift the water. Though varying in detail, chain-pumps are of two principal kinds—one, in which cups or buckets are attached to the band (as has been used from ancient times for irrigating), and another kind where mere flaps are hinged to the band, against which they lie flat while descending and project while ascending. These pumps are not often used, but are convenient sometimes for pumping dirty water in public works or excavating operations, as they will not choke readily. The working barrels and chains are made in about 10-ft. lengths, and can therefore be adjusted to suit an altering depth during excavation. They are

How applied.

generally driven by a belt from a portable steam-engine, but sometimes, especially for irrigating, by oxen or horses. **How driven.**

All the pumps that have been described in the preceding pages, have some moving mechanism through which the power is applied to the water; but there are other kinds of apparatus by which water is raised without any moving engine. Thus in the liquid ejector and sand-pump liquid is raised by the direct application of compressed air, and in a diving-bell or caissoon the water is driven out in a similar way. Steam may be also applied to the raising of water by direct contact. The *Pulsometer-pump* is an ingenious application of an old principle. In this machine there are two chambers, and the steam being admitted to one of them, forces up the water which is within it. The steam, becoming condensed, forms a vacuum, into which the water from below ascends while the upward forcing process is being performed in the second chamber, and thus by a succession of automatic pulsations the pumping continues. As these pulsometer-pumps can be suspended by a chain sling, and can be easily connected with a hose for steam supply and a hose for bringing up the water, they are useful where ordinary pumps have been stopped by being submerged, as well as for other temporary purposes. The prices range from about £12 for a small pulsometer capable of raising 10 gallons of water per minute, to about £50 for one raising about 150 gallons; and so on to about £200 for one raising 1,000 gallons per minute, these prices being exclusive of boiler and piping. As these pumps depend upon a vacuum, they cannot lift more than about 25 ft.; but according to the steam-pressure at command, they will force to a maximum height of about 80 ft.. They have also the advantage of pumping thick or dirty water without choking. Machines worked on this principle, though very convenient in some cases, are not to be compared with more usual kinds of pumps under ordinary circumstances, as they consume much more fuel in proportion to the work done, and cannot be conveniently applied for any but moderate lifts.

Other methods of raising water.

Without moving parts.

See SAND-PUMP.

Pulsometer-pumps.

How applied.

Consume much fuel.

The *Steam-Injector*, which was introduced about the year 1855, adapts and applies certain natural laws by which a jet of steam concentrated in a peculiar way will draw up the water from a reservoir, and force it into a boiler against the steam-pressure there. Injectors find their chief application in locomotives and those other engines where space is very limited, but in many cases engineers, even if an

Steam-injector.

For feeding boilers.

injector be supplied, prefer to have in reserve an ordinary feed-pump. Many modifications and improvements have been made in the steam-injector since its introduction, and the cost has been much reduced, so that an injector suitable for supplying the boiler of a 100-horse power engine, or that of a full-sized locomotive, costs (1880) only from £10 to £15, and the price diminishes to £5 for boilers of 10-horse power.

Improved and cheapened.

Water elevators.

For lifting water to tanks of engines.

See Chap. XXI., RY. EQUIPMENT.

Machines somewhat similar in kind to the injector, but known as *Elevators*, are used for lifting water to a moderate height where there is no resisting pressure. Such machines find their principal use on locomotives and traction-engines which have to carry a store of water with them, but which have not always access to an elevated tank or water-crane. By merely lowering a hose into a stream or well, and admitting steam to the apparatus, water may be drawn up as much as 25 ft., according to the steam-pressure at command.

Choice of pump, how determined.

See page 48.

See page 181.

To enable an engineer to decide upon the kind of pump most suitable for a particular purpose, and upon the size and power for attaining certain results, the following information is necessary; and although many of the points to which attention is directed may appear self-evident, those engineers and manufacturers who have to supply machinery for foreign countries know how frequently the most rudimentary but necessary particulars are omitted from the instructions furnished to them. The particulars already enumerated for steam-engines should be read in conjunction.

Size and power of pump.

Depends on height as well as quantity.

See page 203.

1. The power or capacity required in a pump depends upon two main points: the number of gallons to be pumped per minute, and the height to which the water is to be raised. These factors multiplied together tell the aggregate number of foot-pounds to be overcome. Thus the same horse-power is required to raise 1,000 gallons 100 ft. high in a minute, as 2,000 gallons 50 ft. high, though for the former the pump must have parts stronger to resist the higher column of water, and for the latter the pump must be double the size; but although this is obvious to engineers, the height to be lifted is not unfrequently omitted by would-be purchasers of pumps as a point of little importance, although not only the power or capacity but the kind of pump depends upon it.

Position of pump.

2. The position of the pump in regard to the source of supply and the place of delivery. The pump is in some cases placed at the level of the source, in others at the level of the delivery, and in others

between the two. An engine on the border of a lake, pumping water to a reservoir on a hill; or a pump at a bottom of a mine, raising water to the surface, are examples of the first kind. An ordinary domestic pump, raising water from a well; or a pumping engine on the ground-level raising water from a mine, are the examples of the second kind. A pump drawing water from a well, and forcing it to a reservoir on a hill, is an example of the third kind. The relative level of the water to be lifted and of the engine-house floor or ground level are most important circumstances in the design of pumping machinery. The horizontal distance the water will have to travel is also a circumstance which should be communicated to those concerned; and if the pipes are already made or decided upon, their diameter should be stated, because by the length of the pipes and their diameter will the friction to be overcome be determined. This is very important, as sometimes the friction requires greater power to overcome it than is needed for the lifting of the water. The above particulars may be conveniently given on a plan and section of the site and place of delivery, showing the various levels.

Levels of source and delivery. **Length of pipes.** **Diameter of pipes.** **Friction of water.** **Plan and section of site.**

3. The purpose for which the pumping is required—for instance, whether a pump is for irrigation or draining; or, if for some manufacturing process, the nature of it, as brewing or dyeing; or, if for water-supply, the general conditions which have to be fulfilled; and in any case it should be stated whether the service is to be permanent or temporary, whether intermittent or regular. It is these latter circumstances which generally determine whether cheapness in first cost or economy in working and long endurance are to guide the choice.

Purpose. **Permanent or temporary.**

4. The kind of water to be raised—whether clean or dirty, fresh or salt, hard or soft, hot or cold, whether it contains acids or strong chemicals; all these circumstances having weight in determining the form and material of the parts with which the water will come in contact. Tar-pumps, soap-pumps, and pumps for strong acids or alkalis are made.

The kind of water. **Special pumps for deleterious liquids.**

5. The space available for the pump, for the motive-power, and for the suction and delivery-pipes. Pumps have often to be fixed in inconvenient places, as in mines or tunnels or wells, and the choice of apparatus may have to be guided or modified by some secondary circumstance of this kind, instead of by those which are connected with the primary purpose of pumping.

Space available.

6. The motive-power which is available or which is to be supplied.

Motive power.

If the power is already provided, it should be described as well as the means proposed or suggested for connecting it to the pumps; and if the motor be not contiguous, the means available for transmitting power to the pumps. If a motor is to be supplied, then the kind of force available should be described. If steam from existing boilers, then the pressure and capacity; if new boilers are needed, the kind of fuel; if water or wind power, its extent and direction; if manual force, the strength as compared with English workmen or some other standard; if by oxen or horses, their kind and capacity; if by shafting, its position, diameter, and speed.

Available force.

Buildings and foundations.

See page 182.

7. If settings or buildings of brickwork or masonry are needed, the nature of the soil for foundations, and the kind of building material which are obtainable and appropriate, should be described.

Fire extinction and fire-engines.

Among the numerous and various purposes for which pumping-engines of special kinds are required, *Fire-extinction* has an important place, and invention has been stimulated from time to time by the occurrence of some great disaster which might have been prevented or mitigated by a prompt supply of water. The apparatus most suitable must obviously depend upon local circumstances, of which the principal one is the nature of the water-supply. The tendency of municipal bodies to construct or purchase water-works rather than leave them to private enterprise, arises almost as much from this cause as from those connected with the supply of water for general purposes; and even where, as formerly, a monopoly or concession is granted to private persons or joint-stock companies, the sufficiency and suitability of the supply for fire-extinction are among the principal conditions imposed,

Depend on water supply.

See WATER WORKS *in Part I.*

Quantity of water consumed.

Supply must be always ready.

Pressure in main.

The actual quantity of water abstracted from the public mains for fire-extinction bears so small a proportion to that taken for general purposes (in London $\frac{1}{100}$ part suffices) as to need no consideration in the calculation of the total supply; but it is obviously important that the water shall always be available in sufficient quantity at any one time or place. As one means to this end, there should be such pressure as will cause the water to fill the main pipes at all points in their course, and to rise in a hydrant to, at any rate, such a height above the street level as will supply the tank or suction-hose of a fire-engine; this being generally assured by the more stringent condition that the water—for domestic purposes—shall rise to the top of the highest houses. By the modern system of water-supply in towns

such a pressure is provided, but it is much below what is necessary, without the aid of an engine, for fire-extinction.

Not alone sufficient.

Water in pipes flows to the level of the reservoir or source from whence it is supplied; but though in this way water from a reservoir 100 ft. high will, if unrestrained in its course, rise in time to the top of a house of similar height, it will, if discharged by means of a nozzle on the main as a jet into the air, require a head of water of 180 ft. to enable it, under the most favourable circumstances, to rise 100 ft., or, in other words, the pressure necessary to force water in the air 100 ft. is nearly double that which would take it the same height through a pipe. For lesser heights the proportion is diminished, a 40 ft. head of water sufficing to force a jet about 33 ft. into the air.

For fire-jet.

Pressure needed.

But where the pipes are also used for general purposes, even this theoretical proportion of jets to head or pressure is generally unattainable, because the continued abstraction of water reduces the effective force or impetuous rising power necessary for a jet. Moreover, the pressure of the water is further diminished by the friction during its passage through the mains and afterwards through the hose which conducts it from the main to the ejection-nozzle, for the pressures just stated are those necessary at the actual orifice of ejection.

Fluctuating pressure in supply pipes.

Approximately, one foot of head, or nearly ½ lb. per square inch of pressure, is required to overcome the friction of every 4 ft. of hose when 150 gallons per minute are being forced, and if besides horizontal distance, the hose be raised, the vertical distance of course consumes part of the head or force of water, and diminishes that available at the nozzle.

Friction of water in hose pipe.

As the mains in many towns are supplied from reservoirs high enough for fire-extinction if the force were always available, some engineers recommend a separate service of water for fire-extinction only; while by others it is proposed to use the same pipes for the supply of potable water to houses, leaving the water for municipal, manufacturing, and ordinary domestic purposes to a separate service.

Separate service for fire-extinction.

Fire hydrants.

A constant high pressure in the fire-mains being thus assured, it is then necessary to place hydrants numerous enough to ensure one being always so near to a fire as to render long lengths of hose unnecessary. This plan of numerous street hydrants has been adopted in the City of London; but while it affords a ready supply to extinguish a fire speedily, yet for any considerable conflagration, owing to the low pressure at command, it is only an adjunct to the fire-engine.

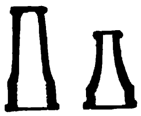
As in London.

Fire-engines still required.

But the conditions necessary for fire-jets direct from the main are found or adopted so rarely that there are very few towns where fire-

engines can be dispensed with; even where the reservoirs are at so great a height as 400 ft.

Form of jet.



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Ejection-nozzle.

The effectiveness of a jet depends a good deal on the form and size of ejection-nozzle. It is necessary to concentrate the force of the water at an orifice of small diameter, in order to obtain impetus for a high jet. Even where the water is wanted at a low level or for a horizonal discharge, such an impetuous jet has more effect than the same amount of water merely poured or sprinkled on the fire. The orifice, or nozzle, is generally of some diameter between $\frac{1}{4}$ in. and 1 in. for manual-engines, and between 1 in. and 2 in. for steam-engines. The larger sizes allow the greatest amount of water to pass, but a much stronger pressure is necessary to force the jet to the same height as is possible with a nozzle of smaller diameter. But if a very high jet be required, then a larger nozzle is essential, demanding an abundant supply of water at great pressure, because small jets—whatever the pressure—are dissipated into spray at a less height than would a thicker column of water with the same proportionate force behind it. Even in still air no pressure would send a jet $\frac{1}{50}$ in. diameter more than a few feet from the ground, while from a nozzle of 1 in. a jet 100 ft. high could be discharged. It is often necessary during a fire to change the nozzle in order to vary the height of jet.

Diameter and force.

Height of jet.

Equable flow maintained.

To render the jet of water from a fire-engine as constant as possible, it is usual to have two or three pumps, and by attaching to the delivery-pipe an air-vessel to receive the shock of each stroke, still further to maintain an equable flow of water. The measure of capacity in a pumping-engine is seldom stated by horse-power, but by the quantity of water which can be forced per minute to a certain height, and in a fire-engine, as has been seen, the height of the jet is with a certain force less than the height which water will rise in a pipe. The difference can, however, be calculated on the data just given, if due allowance be made for the friction in the hose. The best engine is that which will deliver a given quantity of water in the most equable and continuous stream; for if the pressure vary, some of the water will not reach the desired place, and water broken into spray, even if sent with great force, is not so effective as the same quantity in an unbroken jet.

Quantity of water per minute.

Must be equable and continuous.

Fire-engines.

Fire-engines are made of sizes rising by numerous gradations from the small hand-pump to the powerful modern steamer. As an immediate though small supply of water is far more useful in extinguishing a fire than a great supply after the fire is advanced, the

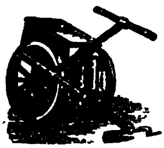
smaller pumps are extremely useful, especially in places remote from public fire-engines. Portable pumps of this sort, resembling those for watering gardens, cost from £3 to £7, according to their capacity, which ranges from 5 to 12 gallons per minute to a height of 30 ft.

Hand-pumps.

For municipal or public purposes fire-engines on wheel carriages are of course necessary; and such engines are made of various sizes, but there is not much variety in the types which in England have been found to be best, although there are variations in the patterns and details of different manufacturers. The body and wheels are made of wood, painted and varnished, but for hot climates every part is generally made of metal. Engines on two-wheeled carriages, small enough to be drawn by hand, and capable of forcing from 50 to 80 gallons per minute to a height of from 50 to 100 ft., cost from £40 to £80. The exact quantity of water and height of jet depend on the number of men at the pumps, handles for accommodating from six to fifteen men being generally provided. Curricle fire-engines, as these are called, may be advantageously fitted with shafts for one horse, and they can then be increased in size, so as to accommodate 20 men at the pump-handles, a force great enough to eject 100 gallons per minute 100 ft. high—the price ranging from £70 to £100. Even in towns or at fire-stations where powerful engines are available, these small light engines are very useful for putting out small fires, and, if quickly despatched and set to work, will often render the larger engines unnecessary. The employment of these engines for small conflagrations leaves the large engine available at the station for more serious fires.

Public engines.

How made.



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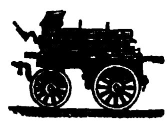
Curricle engines.

Prices.

Where useful.

The pumps and other apparatus of a fire-engine of any but the smallest size are best accommodated on a four-wheeled carriage, and this arrangement is that most generally adopted for municipal stations. The pumps are provided with folding handles, which when extended for use can receive and utilise the force of numerous men. The smaller of such engines, costing about £70 will; with from 8 to 10 men, force about 50 gallons 80 ft. high per minute. The larger sizes, costing about £200, such as are used by the London Fire Brigade, will, with 40 to 50 men at the pump-handles, force 200 gallons 150 ft. high per minute, but this height is seldom obtained, as much of the force is lost by friction, according to the length of hose between the pumps and the nozzle.

Engines on four-wheel carriage.



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As in London.

The working of fire-engines by *steam* was tried as early as 1830, but was not carried to practical success till thirty years later. During

Steam-power.

the interval, the great need for such machines on the one hand, and on the other, the examples afforded by the application of steam to portable engines, cranes, winches, and other separate purposes, stimulated invention which ultimately proved successful; the advantages of steam as compared with manual force being nowhere more manifest than in fire-engines. A pumping-power is concentrated in one steam-engine equal to that of numerous manual engines; a large quantity of water may be discharged so speedily as in many cases to overpower a fire too great for a manual engine; while if the fire be prolonged, and continuous pumping be required, the steam-engine is not only more serviceable but at a fraction only of the cost of manual pumping. Five men may be reckoned as equal to one-horse power, and to equal the effect produced by the consumption of one ton of coal in a steam fire-engine, a concentration of manual engines would be required, involving an expenditure for labour (reckoning 1s. per hour per man) of £20 or more.

Steam fire-engines. *See Vignette, page 197.* **Advantages.** **Power as compared with manual engines.**

In regard to power, steam fire-engines will, according to their size, discharge from 300 to 1,500 gallons of water per minute to a height of from 100 to 200 ft.; and as the maximum height of jet is seldom required, the force is usefully exerted to overcome the friction of great lengths of hose, and to supply numerous jets. The hose-friction, which has been already referred to, renders it almost essential, when manual engines are employed, that the water-supply shall be near the fire. But a steam-engine will work effectually as far as 800 yards from a fire. In towns or districts where numerous and suitable hydrants are not available, the power of the steam-engine in this respect is of great service, as the supply may be taken from a river, pond, or reservoir, at even half a mile distance. As it is convenient to use ordinary hose of moderate diameter, two to four lines of hose, each terminating in a jet or nozzle, are necessary to utilise the force of the engine. If the force of the engine has to be concentrated on one jet, the hose and jet must be of large diameter, or the hose will burst.

Quantity and height of jet. **Power to force long distance.** **Numerous hose pipes and jets.**

In the construction of steam fire-engines, the essential conditions are that, with a prescribed weight, which must be moderate to allow of easy draught, there shall be the maximum power, and so applied by suitable pumps as to give out, as measured in quantity and height of jet, a weight of water equivalent as near as may be to the horse-power. The machine employed should be capable of working continuously for many hours without undue heating or friction, and the working parts simple enough to avoid the risk of derangement, even

Qualities needed in engine. **Lightness.** **Power.** **Durability.**

under rough usage. The furnace and boiler should be so constructed as to allow steam to be generated very quickly, and a full working pressure to be maintained without undue exertion to the engine.

Quick in raising steam.

See page 165.

These conditions are met very fairly in the best modern engines. There are many varieties in detail--single or double steam-cylinders; single, double, or treble pumps. As it is important to save in bulk and weight, and to generate steam very quickly, the boiler is multi-tubular, affording great heating surface and continuous circulation. In raising steam from cold water, three-fourths of the time is occupied in bringing the water to the boiling point; and to save time, it is usual in London, while the engine is not at work, to keep the water in the boiler always hot by having a jet of gas constantly alight in the furnace. When the engine is called on duty, the gas-jet is removed, wood and coal substituted, and the steam is raised to a working pressure of about 100 lbs. per inch in five minutes, or by the time the engine reaches the fire. But even from cold water this pressure can be attained in about fourteen minutes, and seldom in a less time, if the boiler have sufficient water in it.

Varieties in kind.

Boiler.

Time needed to boil water.

Water always kept hot in boiler.

Steam fire-engines, as made in England, are kept as light as possible by the use of steel and high-class iron, and being mounted with springs on a four-wheel carriage, can be drawn rapidly by two horses. The smaller sizes, costing about £400 each, weigh about 1¼ tons, and the largest size, costing £1,500, about 3 tons. When packed for shipment, the measurement tonnage is about five times the weight tonnage, the packing adding 2 to 3 per cent. to the price. An additional expense of £50 and upwards is necessary for suction-pipe and hose, according to the length required. In addition to the various accessories necessary to the working of the fire-engine, and which are included in the prices which have been here stated, there are numerous other articles of equipment, such as hose-pipe, ladders, tools, and buckets. About 12 ft. of suction-pipe is included in the ordinary equipment of the engine, but the delivery-hose has to be purchased separately.

Weight of steam fire-engines.

Prices.

See page 35.

Extra for hose.

Accessories.

The efficiency of a fire-engine depends greatly on the quality of the delivery-hose, and it has often happened that when all other parts of the apparatus are in good order they have been rendered useless at a critical moment by the hose bursting. Hose is made of canvas, rubber, or leather, and in either case the strength necessary and the consequent cost are determined by the head of water or pressure it has to withstand. The diameter of delivery-hose varies from

Quality of hose important.

Material for hose.

Diameter.

$1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., the lesser diameter being usual for small engines, and 2 in. to $2\frac{1}{2}$ in. for town fire-engines. Canvas hose can be made in lengths up to 500 ft., and costs from £7 to £9 per 100 ft., including the metallic connections. Leather hose is usually made in lengths of 40 ft., and costs from £7 to £9 per 40 ft. But though hose of either of these materials can be made strong enough for the maximum pressure usual in a fire-engine, the real value for actual service depends upon the durability of the hose, and in this respect leather has been proved to be best. Canvas is liable to rot after two or three years' service, and the vulcanized rubber hose, owing to the method of manufacture, is also liable to fatal deterioration. It is not the mere pressure during use, but the wear in dragging along the ground, alternate dryness and moisture, and extremes of heat and cold which cause decay. On the other hand, leather hose is much more expensive than other kinds, and needs constant attention in cleaning, oiling, and ventilating to keep it in order. These circumstances are well known to experienced firemen, and although canvas or rubber have proved sufficient under favourable circumstances, copper-riveted leather hose has been adopted in most cases for public service in towns. In 1880, however, a new combination of rubber-lined canvas was introduced, which appeared so good as to justify its trial for a time by the Fire Brigade of London. It costs from 20d. to 24d. per foot for the diameter of $2\frac{3}{4}$ in. usual in London. From past experience, however, its permanent efficiency is doubtful, though if it is found to need less attention than leather, the saving in trouble and expense might justify the cost of more frequent renewals. The new hose is at any rate less damaging than leather to the premises through which it often has to be dragged to reach a fire.

Canvas hose. **Leather hose.** **Causes of decay.** **Leather expensive.** **But generally used.** **Rubber-lined canvas.**

Hose carried to fire. A certain amount of delivery-hose is generally carried on the fire-engine; but sometimes, where the length is great or numerous jets may be required, extra hose must be held in readiness, and therefore separate wheeled carriages are provided for carrying it. The hose-reels, as they are called, cost from £15 for those drawn by hand to £50 for the large carriages for two horses.

Hose-reels.

Organization for fire prevention. The following particulars are necessary for the elaboration of a scheme of fire-extinction, for the organisation of the men and the choice of apparatus :—

Size of town. 1. The size of the town or district, as shown upon a plan, and the population.

Water supply. 2. The nature of the water-supply; the abundance or otherwise of

water; and, if the supply be from pipes, the pressure which is maintained. The lines of pipes and positions of hydrants should be marked on the plan.

3. A description of the kind of hydrants or outlets available for fire-extinction. **Hydrants.**

4. The average and maximum height of the houses.

5. The material of the houses—wood, stone, or brick—so far as regards inflammability. **Kind of houses.**

6. The climate. If dry, whether it increases the inflammability of houses or renders wood-work in the engines inexpedient; if cold, whether the pipes and other apparatus will be exposed to frost. **Climate.**

7. The existing means of fire-extinction; and the experience of the past in regard to fires, so far as it will assist a choice of means for the future. **Existing means.**

8. Under whose control or management the firemen and apparatus will be placed. **Control.**

9. The kind of roads, so far as it affects the choice of vehicles. **Roads and horses.**

10. The kind of horses or other draught animals available for dragging the engines.

If floating fire-engines are wanted, then, in addition to the above particulars, the following also are required:— **Floating engines.**

11. A plan of the river, dock, or harbour where the engine will be used, showing the buildings or shipping to be protected. **Plan required.**

12. The strength of current or flow of tide; and the depth of water, so far as it may limit the approach of the engine to the shore. **Depth, flow, and kind of water.**

13. The kind of water: salt or fresh, pure or dirty.

14. Whether there are land approaches by which engines on shore can come to the aid of the floating engines. **Land approaches.**

15. Whether self-propelling power is to be applied, or whether the towing by boat or steamer is to be depended on. **Propelling power.**

Sometimes pumping-engines are fixed on a barge, but unless for use in a dock or other limited area, propelling power is essential to its efficiency. **Engines fixed on barges.** Sometimes a fire-engine is placed on a small steamer which has been made for some other purpose; but there are various advantages in detail which render a special and fully-equipped steamer preferable. **Complete steamers best.** Small floating engines, without propelling power, such as are used sometimes in docks can be obtained for £1,000, but the more usual kinds cost from £2,000 to £5,000. **Prices.**

In connection with any apparatus for the extinction of fire, it is essential not only that everything shall be in good order for immediate **Fire apparatus kept in order.**

use, but that those concerned shall be regularly practised in using it. Too often in places where fires occur seldom, both conditions are wanting, and a fire obtains great way before sufficient water can be brought to bear. Even where the importance of keeping the apparatus is appreciated, the want of readiness in the users limits and sometimes neutralises the advantage. Thus in warehouses, banks, and factories, the hydrants, hose, nozzles, and buckets are often conspicuously displayed, but as many years may elapse before they are called into service, the hose may be stiff and rotten, the valves too stiff to turn, and unskilled and inexperienced attendants may be unable to connect or use the several appliances. To be of real effect, the apparatus should be regularly practised, and though irregular periods of trial might be best for accustoming the workmen to sudden calls, neglect or discontinuance of practice is best prevented by having fixed days, monthly or quarterly, on which the apparatus can be employed for washing the roofs, windows, or walls, or watering the streets, so that those watchmen, foremen, or others, who would most likely be called upon for actual service either in the day or night, may know exactly what to do. Ten gallons of water employed immediately will have more effect than 10,000 gallons when the fire is raging.

Users often unready. **Constant practice necessary.** **Apparatus used.**

The cost of a fire establishment depends mainly on the completeness and suitability of the water-supply and apparatus, on the local peculiarities of the town, houses, and streets, but also to a large extent on the organisation and drill of the men. Only by attention to the latter point can the highest efficiency be obtained from a given expenditure. Exclusive of capital outlay for water supply, the following was in 1876 approximately the expense in four of the large cities of the world, reckoned per 1,000 inhabitants:—London, about £23; Paris, about £50; New York, about £230; Chicago, about £200.

Cost of fire establishment. **In large cities.**

Tanks. **Cast-iron and wrought-iron.** **Advantages of each.**

Tanks or cisterns are made of cast-iron, wrought-iron, zinc, slate, and wood; but for engineers' purposes, only iron tanks need consideration here. Cast-iron is better suited than wrought-iron to withstand rust; its greater substance allows more margin for waste by rust; the pieces of which a cast-iron tank is composed are easy for carriage, and can be cheaply and effectually joined together. Wrought-iron tanks can be made with thinner plates than cast-iron, and are therefore lighter for carriage; they are less liable to sudden fracture; the joints are less obtrusive, and are free from certain objections against flanges and bolts. Small tanks are generally made

of wrought-iron, as they can be transported whole without damage, but large tanks are seldom made of wrought-iron, except where lightness for transport is of great importance, or where there are special circumstances rendering cast-iron undesirable.

Cast-iron tanks.

Cast-iron tanks are made of rectangular plates, generally of some size between 3 ft. and 5 ft., and in thickness between $\frac{1}{2}$ in. and $\frac{3}{4}$ in. It is generally endeavoured, in designing a tank, to make the plates of uniform size and shape, the dimensions of length, width, and depth being, where feasible, of some common divisor. For instance, 4 ft. is a convenient unit for this purpose, the width and length being then 8 ft., 12 ft., 16 ft., 20 ft., or other multiple. Unless for some special purpose other than that of storage, or except superficial space be limited, deep tanks are to be avoided, and the great majority, whatever their cubic capacity, are generally between 3 ft. and 6 ft. deep. As the pressure of water on each square foot of surface is determined not by the superficial extent of the tank, but by the head of water, the strains to be provided against, and the consequent cost and risk of breaking, increase rapidly with the depth of the tank. It is necessary, in all tanks more than about 6 ft. long, to tie the sides together by iron rods placed across the tank, and angle-stays or brackets are inserted to stiffen the vertical sides. Circular tanks, though more expensive and generally less convenient than rectangular tanks, are stronger against internal pressure.

Shape and size.

Deep tanks to be avoided.

Tanks must be tied and stiffened.

Tank plates joined by flanges.

The plates of cast-iron tanks are fastened together by flanges and bolts, and the question has to be settled in each case whether the flanges shall be inside or outside the tank. The pressure from within the tank tends to tighten inside flanges and to open outside flanges, but tanks should be so strongly made as to render this of no consequence. The smooth, neat appearance of the outside of a tank, when the flanges and bolts are all inside, sometimes leads to the adoption of the latter plan, which in England is that generally adopted for storage tanks at railway stations; but as outside flanges are best, they should be adopted where possible, especially where the purity of the water is of importance. There is the great disadvantage with inside flanges that the bolts are exposed to rust; and the flanges, especially those on the bottom, hold dirt or sediment, and hinder the easy cleaning of the tank. A smooth clean surface is sometimes given by a lining of Portland cement flush with the flanges. Tanks are sometimes so situated that flanges outside would be inaccessible for caulking and painting, and where tanks have to be

Inside flanges.

Outside flanges best.

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Cement lining.

fixed in confined spaces, inside flanges allow the whole space to be utilised, while outside flanges not only project but require room for caulking. Even where the sides can be caulked from the outside, the underside of the tank bottom, where it rests upon its supports, is frequently inaccessible. But outside flanges can, if shaped for the purpose, be also caulked from the inside, and as this is often necessary for the bottom of the tank, some engineers, for the sake of uniformity, caulk outside vertical flanges also from the inside.

Accessibility for caulking.

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Plate edges planed.

In fitting together cast-iron tanks the plates may be so accurately planed at their edges as to need only a smearing of red lead to be water-tight when bolted together; and in such a case the plates should be planed to template so as to be interchangeable. The more usual plan, however, is to fit the edges of the plates with approximate accuracy only, and then to make the joint by caulking between the flanges with cement formed of iron borings. Cast-iron tanks so jointed remain permanently water-tight; but they should be periodically examined to see that the bolts, ties, and stays are in good condition. For want of such care cast-iron tanks will fail from corrosion of these parts, and the sudden giving way of the tank. The chances of such accidents are so remote, if moderate care be exercised, as not to outweigh the many advantages of cast-iron in the majority of cases; but where a tank is so situated—as, for instance, over a hospital or school—that its failure, and the sudden falling of many tons of water, would cause loss of life, then wrought-iron tanks, which would give more signs of yielding before actual fracture, should be used. But such cases need seldom arise, for where large tanks are elevated, they should be on buildings not used for habitation.

Jointing.

Caulked joints.

Sudden failure of cast-iron tanks.

Precautions.

Fracture from sudden changes—hot to cold.

Cast-iron tanks are liable to fracture by great and sudden changes of temperature. Thus, in breweries and dye-works, tanks may have to be filled alternately with hot and cold liquor; and if the change be sudden—and especially if the liquid in entering impinge on one plate—the metal will break. It is therefore generally expedient to employ wrought-iron tanks for such purposes. Sometimes, however, it is convenient for other reasons to use cast-iron, as, for instance, in the shallow cooler-tanks of a brewery. In such cases the ordinary iron cement or rust joint is not the most appropriate, and planed joints are the best; but as it is almost impossible to prevent some slight leakage as the tank expands, some absorbent material such as paper should be interposed in addition to the smearing of red lead usual in such joints, as it intercepts the leakage.

Special jointing necessary.

Cast-iron tanks can generally be purchased at from £7 to £12 per ton above the current rate of pig-iron, these rates allowing for the bolts and stays; but within these limits the exact price will depend on the thickness and weight of the plates, whether they have to be machined, whether the various parts repeat so as to avoid pattern-making, and whether numerous outlets or irregular accessories are needed. The labour in fixing, caulking, and painting a properly-made cast-iron tank costs from £1 10s. to £3 per ton.

Cost of cast-iron tanks.

Cost of fixing.

As each cubic foot holds 6¼ gallons, the size of a tank to contain a given quantity can be easily calculated, and an approximate estimate of weight can be made by assuming a thickness all over of about ¼ in. more than the actual thickness of the plates to allow for the weight of the flanges and ribs. Thus if the plates be ½ in. thick, as in small shallow tanks, then instead of 20 lbs. per square foot, 28 lbs. would be about the total weight; or, if the plates be ⅝ in. thick, 35 lbs. should be assumed instead of 25 lbs.

Size or capacity of tanks.

Weight of plates.

Tanks are supported either upon brick walls or iron columns, and in either case, if the tank be more than 6 ft. square, a framing of girders should be so arranged as to give bearings not too far apart. Rolled joists are convenient and useful as cross supports. It is usual to place the girders immediately below the joints of the plates, this plan being feasible where the caulking is from the inside. Each cubic foot of water weighs 62½ lbs.

Supports for tanks.

Girders.

See page 148.

Weight of water.

Wrought-iron tanks are made of plates (generally termed sheets when thinner than $\frac{3}{16}$ in.) from $\frac{1}{12}$ to ⅜ in. thick, according to the size of the tank. The plates either lap over each other, or have butting joints, and are riveted together like boilers, and the seams closed with a caulking tool. The trouble and expense of riveting at the site are the chief reasons why wrought-iron tanks are so seldom used of sizes larger than can be transported whole. Wrought-iron tanks can generally be purchased at rather less prices than those of cast-iron, the price per ton being about double, and the weight less than half; but the expenses of fixing are rather greater, so that the final cost is about the same. Small open cisterns or closed tanks are transported whole, but the limit of size depends, of course, on local circumstances and the means of carriage; but even where possible, the great space occupied is an inconvenience, especially in stowing for sea-carriage, though the space may be utilized by packing other goods inside or, in the case of open cisterns, by "nesting" together one inside another. The manufacture of wrought-iron tanks has become

Wrought-iron tanks.

See page 144.

Cheaper to buy but dearer to fix.

Small tanks exported whole.

a special branch of trade, and large quantities are made for storing water on board ship, for holding oil, and for numberless other purposes. From 50 to 500 gallons is the range which includes the small sizes most in demand, and it is customary to state the cost by the capacity, sales by weight seldom taking place, except for larger sizes. The price is not so immediately influenced by the price of raw material as in the case of cast-iron tanks, and when the current price for tank-sheets is from £9 to £12 per ton, the current rates for small open cisterns will range from 7d. to 5d. per gallon up to a capacity of 300 gallons, diminishing to 4d. for tanks holding 600 gallons. If the tanks be covered, an extra cost of about a penny per gallon is incurred. Prices in printed lists are generally much higher than the above, but as in the case of tubes, are subject to discounts. It is usual to coat small tanks with zinc at an extra cost of about 10 per cent., but such coating is not permanent unless itself protected by painting. Large tanks of wrought-iron are made of plates varying from $\frac{3}{16}$ to $\frac{3}{8}$ in. thick, and cost from £8 to £12 per ton more than the rates current for tank plates.

Cost of small tanks.

Small tanks galvanized.

Cost of large tanks.

See page 143.

Particulars for designing tanks.

In order properly to design a tank, to choose between cast and wrought-iron, and to estimate the cost, the following information is necessary :—

Capacity. 1. Complete dimensions of length, width, and depth; or instead of these, the capacity in gallons, with any limitations in regard to shape, area, or depth that may be necessary. Such limitation may often be well indicated by—

Situation. 2. A drawing or description of the place where the tank is to be fixed, showing the height from the ground, the nature of the supports, the area available, and whether it is enclosed or open.

Purpose. 3. The service for which the tank is needed; whether for salt or fresh water, hot or cold liquid; the extreme changes of temperature; and whether the tank is to be covered.

Pipes and valves. 4. A description or drawing of any inlets, outlets, pipes, and valves that may be needed.

Supports. 5. Whether supports for the tank are to be supplied.

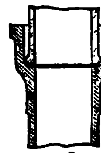
Climate. 6. Extremes of climate and difficulties of transport should be described.

Iron pipes. *Iron pipes*, as used by engineers, may be classed as for water, gas, steam, and rain-water; and for all these purposes cast-iron is the most usual material; wrought-iron being by English engineers generally

employed only for small diameters, or for special purposes; although in France wrought-iron pipes are more frequently used. Pipe-founding, though not a difficult art, requires care and experience to produce sound castings. It is, in regard to its extent, one of the most important of the subsidiary engineering trades; the quantity of pipes made is so great as to render every detail of consequence; and the use of special appliances, which great repetition promotes, has brought the cost of pipes lower than that of castings generally.

See page 235.

Pipe-founding.



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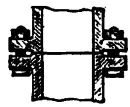
Socket-pipes.

The cylindrical form of a pipe renders it very strong against internal pressure; and the material of cast-iron is well suited to withstand the outer pressure or weight which a pipe has to sustain when buried below ground. Cast-iron pipes, in regard to form, are of two kinds: flange-pipes, and socket or spigot-and-faucet pipes; these being the alternative methods of jointing. Flange-pipes, which are held together by bolts, are used for steam and for high-pressure water, and socket-pipes for gas and ordinary water service.



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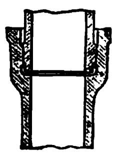
Flange-pipes.

Care in casting.

Must be concentric.

In casting pipes, care is necessary, as in other hollow castings, to ensure the core being concentric, for of course if the core be misplaced and the section of the pipe eccentric, the pipe is weaker, because thinner at one side than the other. Even if still strong enough to withstand a test, the margin of strength is reduced, though there may be nothing in the outward appearance of the casting to indicate the inequality. In spigot-and-faucet pipes, the diameter of the socket is generally sufficient to allow for trifling inequalities in its shape and in that of the spigot, and to afford also some play in laying or adjusting the pipes in a desired line. But the plan is sometimes preferred of turning the spigot and boring the socket (slightly taper), so that they will fit so accurately as to need only a smearing of white lead or Portland cement, the blue lead or other caulking material usual in loose sockets not then being necessary. Machine processes are so cheaply performed that the cost of turning is more than met by the saving in time and expense in laying the pipes and making the joints. But while this plan may be effective for pipes laid level, and on an unyielding bed, it is not suitable for pipes laid on a less certain foundation; for if the bed yield, there is not the play which the wider socket allows, and the tight turned joint will be more liable to break.

Bored sockets and turned spigots.



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Where suitable.

Flange joints.

It is more desirable to make the joint-faces of flange-pipes true by turning; for though by means of rubber or other washers, or by caulking with cement, a tight joint can be ensured though the metallic

face be slightly uneven, there is more trouble in laying the pipes and more risk of leakage afterwards. And as, if the pipes be not turned, the trouble of chipping the irregularities from the faces (a process not so effectual as that performed by the lathe) has to be incurred, it is always desirable to turn them. The leakage by imperfect jointing may be considerable, and yet in buried pipes so invisible and silent as to be difficult of discovery. In the water-supply of towns the leakage sometimes bears a considerable proportion to the total consumption, and not only causes a loss of water but a diminution of pressure. In gas undertakings also, the loss by leakage sometimes equals or exceeds the amount necessary for profit on the capital expenditure.

Turned flanges. **Leaky joints.** *See page 174. Part I.*

The foundry moulds for very small pipes are laid horizontally; for the larger sizes, a slanting position was formerly adopted; but it may now be considered as obsolete, and a vertical position is generally demanded by engineers for pipes over 3 in. diameter; for cores of larger diameter are, unless placed vertically, liable to float or rise upwards in the mould, and make the upper side of the pipe too thin. Moreover, when soundness and closeness of texture in any part of a casting is required, it is an ordinary incident of the founder's art to place that part downwards, because the weight of molten metal compresses that at the bottom, and the air-bubbles and loose sand that may have fallen into the mould rise to the upper part. When pipes are cast vertically, the weight and volume of iron in the runners or conduits through which the molten iron enters the mould are not always sufficient to secure solidity and purity of metal throughout the body of the pipe, though it is generally considered sufficient for this purpose in ordinary castings, and therefore it has become the practice among the best pipe-founders to cast the socket downwards, and to allow a considerable head of metal (chiefly by a prolongation of the spigot end), which is afterwards cut off in a lathe.

Mode of casting. **Vertical moulds.** **Advantages.** **Sockets cast downwards.**

The proper strength and durability of cast-iron pipes are assured—

1. By giving that thickness to the pipes which calculation, based on an assumed tenacity of the metal, shows to be necessary to the diameter of the pipe, and the pressure to be endured. To allow for inequalities in casting, safety in carriage, and wasting by rust, water-pipes are generally designed with a factor of safety, which, if calculated according to the internal pressure they are to endure in working, ranges from 6 to 1 to 10 to 1, according to the purpose to be fulfilled and the opinion of the engineer. For situations where the pipes

Strength and durability, how ensured. **Thickness.**

will not be exposed to rough treatment, a factor of 6 to 1 may be sufficient; or 8 to 1 if for water mains in towns; while in cities where there is heavy road traffic, 10 to 1 is often adopted. **Factor of safety.**

2. By using good iron. The quality of the iron, though often specified, is seldom, except in large or important contracts, really ensured by supervision and tests, and inferior metal may then be used without detection, because it may be amply sufficient to bear the water-pressure test. Iron re-melted from pig-iron in a foundry should be specified (to the exclusion of iron cast from a blast-furnace), and of a strength which will bear on the standard test-bar, already described, a certain load. A weight of 25 cwt. should be the minimum, but this only shuts out very inferior iron, and 28 cwt. may be obtained without difficulty. If a minimum weight of pipe, or great tenacity of the metal is important, as, for instance, for long transport, or to endure rough treatment, 30 cwt. is specified, and for this the iron in some districts is, if used alone, not strong enough, but may be made so by the admixture of superior iron. If it were not for the inconvenience of constant supervision, it would always be advisable to use good iron, as the advantages obtained outweigh the extra cost. A greater test load than 30 cwt., though occasionally demanded for special purposes, is not expedient generally. **Quality of iron.** **Foundry castings.** **Test bars.** *See page 133.* **Quality ensured by supervision.**

3. By proper methods of casting. Although an engineer will generally specify a vertical position for the mould, yet, as the plant and appliances of pipe-founders differ, it may be necessary to verify by inspection before and during manufacture that the specification is obeyed. **Mode of casting.**

4. By verifying the thickness of metal by weighing each pipe. A margin—generally of about 4 per cent. for small pipes of 3 in. diameter, and diminishing to 2 per cent. for pipes of 36 in. diameter—is generally allowed, within which limits any pipe otherwise good will be received; but sometimes it is stipulated that no excess of weight beyond 1 per cent. will be paid for, as it may be expected that the average difference will not exceed this. **Thickness verified.** **Limits allowed.**

5. By examining each pipe inside and out, to see if there are any unsound places; and by gauging and measuring to prove that they are concentric in section, and that the spigots, sockets, or flanges are of proper form and diameter. A disc $\frac{1}{8}$ in. less in diameter than the prescribed bore of the pipe should pass freely inside. **Gauging and measuring.**

6. By testing each pipe by high-pressure water, to detect flaws or cracks in the metal. A pressure equal to a column of water 300 ft. **Testing of pipes by water.**

high (about 130 lbs. to the square inch) is generally adopted as sufficient for this purpose, and this rule is in England so well established, as to be almost an assumed condition in bargains for pipes, and every pipe-founder has testing machines as part of his ordinary apparatus. But for thick pipes, in which the working pressure will exceed 200 ft., a greater test pressure is prescribed, rising to 1,000 ft. where the working pressure exceeds 500 ft. The above tests do not prove the strength of sound and well-made pipes, but are enough to ensure that—within the short time the pipe is under pressure—the water shall penetrate to and discover cracks, flaws, or spongy places. Still further to detect weakness or liability to fracture at such unsound places, it is usual while the pipes are under pressure to rap them with a hammer.

Usual test-pressure.

Objects of water test.

Coating of pipes to prevent corrosion.

7. By coating the pipes inside and out with some preservative compound. Corrosion is specially damaging to pipes, for it not only wastes away the metal but the rust accumulates and, fungus-like, expands (the composition of the water often assisting this), so as to choke the passage-way. So serious are such consequences that many plans of coating and painting have been devised to prevent it. The pipes should be oiled directly they have been trimmed in the foundry before rust has commenced, and then coated. The most successful coating is that known as Dr. R. A. Smith's process, by which the pipes are coated inside and out while hot with a peculiar bituminous composition. This plan, which adds from 2s. 6d. to 5s. per ton to the cost of the pipes, is almost invariably adopted for water pipes, and postpones greatly the decay of the iron. The durability of the coating depends on the efficiency with which it is performed and on the kind of water passing through the pipe. In some cases the coating shows no signs of deterioration after twenty years' use.

Usual method.

Cost.

Efficiency.

Pipe inspectors.

Precautions such as these demand care and knowledge, and inspectors who have had special experience are generally employed. But notwithstanding the care which may be exercised during and after manufacture, it is seldom that a certain proportion of faulty pipes can be avoided, and if such pipes are buried *in situ*, without their faults being detected, they may be the cause of much loss by leakage—often silent and undiscovered—or of expense in substituting new pipes. It is important, therefore, that a line of pipes while being laid, and before the trenches are covered up, should be tested under pressure; convenient lengths of pipe being temporarily isolated and closed for the purpose, a process by which also, in gas-pipes as well

Pipes tested *in situ*.

as in water-pipes, the condition of the joints may be ascertained. The loss of gas by leakage is often very great, and the saturation of the soil in large towns from this cause is an important sanitary question.

Evils from leakage.

See page 223. Part I.

Pipes sold by weight.

Cast-iron pipes are generally sold by weight, and the total cost depends on the thickness of the metal; the cost of carriage being also so determined. A bargain for pipes at a price per ton is therefore incomplete unless accompanied by a statement of weight, which may be specified either by the purchaser or the seller. The weight depends mainly on the thickness, but a little also on the dimensions and form of the socket or flange. In some cases, purchasers who have specified the thickness or weight of pipes and the water-pressure test to be endured, make no other stipulation in regard to the quality of the iron, and for small quantities or unimportant purposes the expense of further precaution may be inexpedient, and a proper quality ensured by dealing only with manufacturers of good repute, and who use iron of known quality. But in important cases, a certain tenacity in the metal, as measured by the weight sustained by a test-bar, is also demanded.

Cost depends on thickness.

Standard weights.

Every pipe-founder has his own standard weights, to which, either exactly or within moderate limits, he is prepared to adhere; but when a rate per ton is the measure of price, a water-pressure test the measure of quality, and no conditions as to thickness, weight, or tenacity demanded, there is no inducement to the founder to save in weight by using iron of high quality and taking due care in manufacture; and pipes so bought will presumably weigh more than pipes bought with prescribed limits in these respects. But bargains are seldom made without limits of weight, and pipe-founders are generally prepared to conform to usual limits, although, of course, the less the weight, the less will be the remuneration which a given price per ton will afford for the labour of making. But even iron of the lowest quality will, as already stated, if cast without flaws, endure the water-pressure test, so that it alone is but a partial protection. Therefore in comparing competitive offers from manufacturers, the lowest price per ton, even if allied with moderate weights and subjection to the ordinary water-test, is not necessarily the cheapest, unless the quality of the iron and the consequent margin of safety and non-liability to breakage be taken into account, as well also as the soundness and concentricity of the castings. In gas-pipes, and frequently also in water-pipes, the working pressure is so small as to need no consideration in deciding

Limits of weight.

Lowest price not always cheapest.

Quality of iron important.

on the thickness of the metal, which has to be determined by other circumstances, such as the substance necessary to ensure soundness in founding, safety in carriage, resistance to external pressure when laid, and endurance against rust. In the case of long carriage or frequent transhipment, breakages are sometimes very numerous, and it is important to provide, either by special insurance or by specific contract with the carriers, for the loss by breakage. Shipowners and others sometimes seek, by special clauses in their bills-of-lading or carriage-contracts, to avoid their ordinary common-law obligations in this respect.

Breakage during transport.

See page 37.

Usual lengths of pipes.

Cast-iron pipes are, in England, made 9 ft. long, when the diameter does not exceed 12 in.; beyond this and up to 48 in. a length of 12 ft. is usual; the length in each case being that which is net or effective when laid, exclusive therefore of the socket.

Table of weights.

Diameter of bore.	Net Length.	Weight each in lbs. A	B
3 in.	9 ft.	108	136
4	9	152	200
5	9	202	275
6	9	256	360
7	9	316	454
8	9	380	562
9	9	450	680
10	9	530	806
12	9	690	1092
14	9	876	1426
16	9	1082	1790
18	9	1309	2200

Spigot-and-faucet pipes, if cast with care from good iron capable of enduring 28 cwt. on the standard test-bar, do not require for a working pressure of 80 lbs. per square in., and a factor of safety of 10, a greater thickness than the following weights in column A imply, and many engineers consider these the minimum weights even for lower working pressures. For convenient comparison all the lengths are stated as 9 ft., but an addition of one-third will give the weight of 12 ft. lengths. The weights in column B are sufficient for a working pressure of 160 lbs. But in the absence of stipulation to the contrary, pipes weighing from 5 to 20 per cent. more are generally supplied by manufacturers, and unless careful and constant inspection can be insured, it is inexpedient to demand the minimum weights given above. Flange-pipes, if of the same thickness as spigot-pipes, weigh from 5 to 10 per cent. more, but they are usually made thicker than socket-pipes, as there is more difficulty in casting (the upper flange forming a lodgment for the impurities in the metal), and therefore some allowance must be made if the flange-pipes are to be as strong as the socket-pipes. The thickest pipes are

Flange pipes heavier.

those—always with flanges—used for the rising mains of deep mine-pumps, which have to withstand an enormous pressure. *See page 202.*

As pipes come within the category of cheap castings, the cost of manufacture bearing a less than usual proportion to the value of the metal, prices follow closely the current rates for pig-iron. Socket (spigot-and-faucet) pipes, which are the kind generally assumed by the manufacturer, in the absence of stipulation as to kind or purpose, cost for all diameters above 3 in. £3 to £4 per ton above the current price of pig-iron; the price of pig-iron ranging in ordinary times from £2 10s. to £3 per ton. The exact prices of pipes are determined by the quantity ordered at the same time, the severity of the tests, and the conditions of delivery and payment. If the sockets and spigots of the pipes have to be bored and turned, from 7s. to 15s. per ton extra is incurred. From 3s. to 6s. per ton is the extra cost for coating with a preservative process. Flange-pipes cost about £2 per ton more than socket-pipes, but the extra expense of turning is about the same. As the low prices at which pipes are sold is owing to the great repetition in manufacture, small or miscellaneous quantities are much dearer. Branch pipes, tees, bends, and other pipes classed as irregular, generally cost from £4 to £5 per ton more than the current price for ordinary straight pipes, and if—as in connection with a pumping-engine or steam-boiler—pipes of various sizes or lengths be required, the ordinary prices are no longer applicable, the special economies of manufacture become impossible, and, as in other classes of foundry work, the price is determined by the cost of patterns and other preparations.

Prices of pipes fluctuate with cost of iron.

See page 33.

Prices of cast-iron pipes.

Extra charges for turning and coating.

Irregular and miscellaneous shapes dearer.

Pipes should be made so exactly to a pattern or gauge as to be interchangeable; and for permanent undertakings where renewals or extensions are likely to occur, as in the case of municipal gas and water works, standard patterns should be established. Pipes made without such rules, even if of the same nominal size, if bought at different times from different manufacturers, involve extra trouble and expense in the laying and in the making of joints. In flange-pipes not only should flanges of a uniform diameter and thickness for each diameter of pipe be prescribed, but it is important also that the position of the bolt-holes should be uniform. In pipes subjected to great pressure of steam or water, the flanges are often cast without bolt-holes, these being afterwards drilled with great exactitude, and the bolts turned to fit. But in the majority of cases, the cheaper plan of making the holes in the process of casting is adopted. Besides making the hole

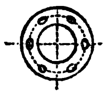
Pipes should be made to gauge and interchangeable.

Holes in flanges.

Drilled holes.

Cast-holes.

larger than the bolt, an additional margin for adjustment is provided by making elongated or oval holes. Templates or patterns for the flange and bolt-holes should be provided for each size of pipes, and in the case of bends and other irregular shapes, the relation which the horizontal axis or other datum-line bears to the setting-out of the holes should be indicated.



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Particulars for designing pipes.

In the absence of a detailed drawing or specification, all or some of the following information (as the nature of the case indicates) should be furnished to the manufacturer, to enable him to make pipes of suitable kind and to estimate the cost.

Size or capacity. 1. The diameter or bore of the pipes, or if this cannot be given, the quantity of water or gas to pass in a minute with a given pressure.

Quantity and kind. 2. The number of pipes required, or the total length in lineal feet; and whether flange or socket joints.

Purpose. 3. The purpose for which the pipes are required. If for steam or water, the maximum working-pressure.

Pattern. 4. If the pipes are to connect with others already fixed, or where some standard pattern is established, a drawing or template of the socket, or of the flanges and bolt-holes, will be necessary to ensure uniformity.

Bends and tees. 5. The number and description of bends, tees, and other irregular forms.

Jointing. 6. Whether the joints of the pipes are to be turned or bored.

Painting. 7. Whether and how the pipes are to be coated or painted.

Testing. 8. The tests to which the pipes are to be subjected.

Rain-water pipes.

Rain-water pipes are made almost as thin as the process of casting will allow, and therefore such pipes are peculiarly liable to fracture during carriage. When, however, they are fixed in place the pipes are strong enough for their purpose, and if kept painted will probably last as long as the building to which they are attached; but if not cast concentric, the thin places will soon be corroded away and the pipes rendered useless. Rain-water pipes have socket joints and are sold by measure of length, and not by weight. In specifying such pipes the bends, swan-necks (almost always needed to clear projections on buildings), and enlarged head-castings which are required should be described.

Sold by measure. **Irregular shapes.**

Wrought-iron pipes.

Wrought-iron pipes (as distinct from tubes) are made of sheet-iron from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. thick riveted, and are used for various purposes where light, strong pipes are required. Thus, they are used some-

times as chimneys in smithies, or for conveying the blast to smithy fires, or compressed air in mines, or as water-pipes for chain-pumps, or in well-sinking operations, as they are light for handling and bear without fracture constant movement and adjustment. In France, wrought-iron pipes of a peculiar kind are made, and are largely used on the Continent for mains in the streets, not only for conveying gas, but also for water of moderate pressure. The pipes are made of sheet-iron coated on both sides with lead, and the seams after being riveted are soldered. The pipes are then covered outside with a thick coating of bitumen. These pipes are light for carriage, will withstand considerable internal pressure, will bend rather than break, and will endure long against corrosion. They are not, however, so strong against outside pressure and the shocks of street traffic as cast-iron, and will not withstand high internal pressure. These composite pipes are made in lengths of 4 mètres, and one end being slightly distended to form a socket, a joint is made by driving with a mallet the end of another pipe into it, the latter having the bitumen partly cut away and a groove left for a ring of hemp and tallow. The pipes are sold by measure of length, and cost in France rather more than cast-iron pipes cost in England, but they are light for carriage and are cheaper in many parts of the Continent than cast-iron pipes made in a local foundry or brought from a distance. Wrought-iron pipes are generally sold by lineal measure. Pipes of sheet steel are (1880) being introduced in England.

Where used. Composite pipes made in France. For gas and water. How made. Advantages. Disadvantages. Customary lengths. Method of jointing. Sold by lineal measure. Cost compared with cast iron.

Tubes are made of iron, steel, copper, or brass; and by engineers are used principally for the flues of boilers, as refrigerating tubes in surface-condensers, and as pipes for steam, water, and gas. Iron tubes are made by bending strips of sheet-iron into the desired form and welding together by a lapping joint, or by welding the edges butted together. The machinery for making tubes is of a very ingenious kind, and the improved methods which have increased the regularity and soundness of the welds have also lessened the cost. Solid-drawn steel tubes are also made, but, considering their much greater cost, have (1880) no marked advantage over welded iron tubes.

Tubes. How made. Steel tubes.

The small diameter of tubes renders them very strong against either external or internal pressure; even a moderate thickness of metal having a tenacity great in comparison to the strains which, under ordinary treatment, the small surface area exposed can bring

Iron tubes strong against pressure.

Thickness. upon it. Indeed, the thickness of tubes is often much in excess of what the pressure would require and is determined by secondary **Connections.** reasons. Thus, in tubes used for conveying steam, gas, or water, the connections are generally made by screwed sockets or couplings, and, as the screw-thread is cut into the metal, the latter must be thick and strong enough to allow for such a diminution of substance. **Boiler tubes.** But for tubes used in boilers and surface-condensers, it is important that the metal shall be as thin as possible, so as to transmit heat readily; and as such tubes do not require a thread cut into them, they can be made of the minimum thickness which, with a proper **Too thin for butt welds.** margin of safety, the strains upon them require. But being thus made thin, there is not sufficient contact surface on the edges to allow an effective butt-weld, and such tubes—if of iron—are lap-welded, while the thicker tubes, with screwed ends, may be butt-welded, which costs less than lap-welding and is not generally considered so secure. The ordinary iron tubes sold by makers of repute without any special stipulation as to quality, and used principally as gas-pipes, are strong enough also for steam or water with a working **Working pressure.** pressure of 10 to 20 lbs. to the inch. But as the failure of tubes arises from flaws in the iron or imperfect welding, which are revealed even by moderate pressure, and as, if there be no such defects, the iron is thick and strong enough to withstand considerable strains, it will generally be found that tubes which will endure 20 lbs. pressure will endure much more; but for higher working pressures than 20 lbs. it is expedient to state the purpose and to stipulate for tubes **Tests for locomotive tubes.** of guaranteed strength. Thus for iron tubes used in the boilers of locomotives an internal pressure of 800 lbs. and an external pressure of 250 lbs. are sometimes specified as tests to be endured without fracture. The thickness of the tubes has to be increased according to the diameter, and even of the same diameter different thicknesses **Hydraulic tubes.** are made, according to the purpose in view. Specially thick tubes *See page 84.* are made for conveying water for hydraulic machines, the working pressure for such purposes ranging from 500 lbs. to 8,000 lbs. per square inch.

Failure of tubes. Well-made tubes seldom burst from internal pressure unless they are weakened by corrosion; but tubes badly welded, or made of inferior material, will sometimes tear open, especially under great pressure. Tubes of inferior iron have often minute surface cracks, which develope under heat or pressure and tear open. Boiler-tubes are the kind most liable to failure; their durability is in any case limited by

the severe service they perform; and if of inferior quality, or if not renewed in time, they will fail by bursting, burning, or by tearing from the plates which hold them. *See page 277.*

Iron tubes are the kind generally employed for marine boilers, though brass tubes are used in the Royal Navy. These brass tubes range from 2½ in. to 4 in. external diameter, and the thickness from No. 7 to No. 11 B. W. G.

Brass and copper tubes.

Brass and copper tubes are either rolled by machinery and the edges brazed together, or they are drawn in such a way as to be seamless. The latter plan, formerly very expensive, has been cheapened, and the tubes so made tend to supersede the brazed tubes. From ¾ in. to 5 in. external diameter are the usual limits of size for brazed tubes, and beyond these sizes they are made by coppersmiths and not by tube-makers. Solid-drawn copper tubes are made up to 9 in. diameter. Solid-drawn brass tubes are made of all sizes between ½ in. and 4 in. external diameter. The quality of brass tubes depends not only on the manufacture, but on the alloy of the brass. Different alloys are used for different purposes, but from 67 to 70 parts of copper to 30 to 33 parts of zinc embrace almost all the combinations; but these metals must be pure to make good brass.

Brass alloy.

Usual lengths of tubes.

Tubes are usually made in lengths of from 14 ft. to 16 ft., and are sold by lineal measure. The price for ordinary iron tubes ranges from about 2d. per ft. for ½ in. internal diameter, to 4d. per ft. for 1 in. diameter, 10d. for 2 in., increasing to about 3s. 6d. for 4 in. diameter, and 9s. for 10 in. diameter. But the great majority of tubes sold are less than 4 in. diameter, and the larger sizes are used only for special purposes. The prices of tubes being stated according to so small a measure of quantity as one foot, ordinary money units of pence and farthings are insufficient to express small gradations or fluctuations in price; and it is the custom of the trade in England to adjust prices by percentages. Instead, therefore, of altering price-lists from time to time, printed lists are established, which remain in force for years, the actual prices at any particular time being arrived at by deducting the discount which is then current. The printed prices are (1880) about double those stated above, but are subject to discounts of from 40 to 60 per cent., according to circumstances.

Prices.

Price lists.

Discounts.

See page 25.

Coated with enamel.

Iron tubes may by a special process be coated inside with enamel, but as this about doubles the cost, the expense is seldom incurred

except when the tubes are used for conveying corrosive liquids. **With bitumen.** Tubes may be coated with a bituminous mixture inside and out for **Galvanized.** an extra cost of about 3 per cent. or galvanized for about 10 per cent. Small copper tubes of about ¾ in. external diameter and about 18 B. W. G. thick, as used for surface-condensers, and larger sizes as used for refrigerators in breweries are sometimes tinned inside.

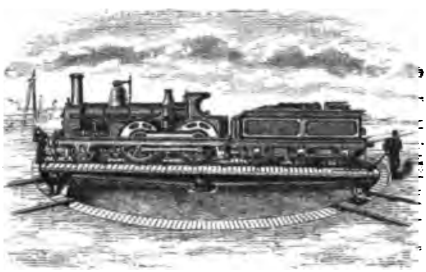
Screwed joints. Each length of tube—if for gas, water, or steam—is screwed at each end; this, with the supply of one connecting-socket, being **Boiler tubes.** included in the price per foot. Boiler-tubes are supplied perfectly plain, without any screwing or other work upon them, and are held in place by passing them through a plate and expanding them in the hole, a taper ferrule being afterwards driven into the tube. To **Annealed ends.** allow of this being done without damaging the iron, the end of the tube is generally softened by annealing. Iron tubes with brass or copper ends are often used in locomotives, as the iron, if attached directly to a copper fire-box, does not form a permanently **Copper and brass tubes.** good joint. Copper and brass tubes (also without screw-thread) are sold by weight, the price varying with the current prices of these metals from 9d. to 12d. per lb.

In purchasing tubes, the purpose for which they are to be used should be stated; if of iron, whether lap or butt welded, and if of brass or copper, whether brazed or seamless. The exact length or the limits of length should also be stated. Bends, tees, and other connections, of which there is very great variety, are sold at prices per piece. It is also necessary to state whether the diameter given is external or internal and (except for gas tubes) the thickness, as there is no established rule as to what is meant when merely the diameter is stated.

[*See also* STEAM-ENGINES: TRANSMISSION OF POWER: *and in Part I.*, WATERWORKS.]

CHAPTER XXI.

RAILWAY EQUIPMENT.



In previous chapters, reference has been made to the inception of Railway schemes, and to the preliminary steps necessary to carrying them out. Even in the first equipment of a railway with material and rolling-stock, the engineer has not, in countries remote from the place of manufacture, always ready access to the terms current for the purchase of material, and it is sometimes difficult, also, after a railway is in operation, to ascertain in the case of extensions or renewals what conditions of purchase are necessary to obtain the best result. It is attempted in the following pages to indicate those particulars which determine price, and which are necessary to the proper choice and purchase of the various kinds of Railway Equipment.

See Part I., Chaps. I., II., III., IV.

Purchase of material.

Rails.

Are of three principal kinds.

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Double-head rail.

Rails of various shapes and sizes have been tried, but three principal kinds were established in the early days of railways, and have formed the rudimentary types from which most of the patterns since adopted have been developed. These are the *Double-headed* rail, the *Vignoles* or *Flange* rail, and the *Bridge* rail. The double-headed rail, so extensively used in England, France, and other continental countries where railways were first constructed by English engineers, was adopted principally for the supposed advantage of allowing both faces to be used; but this pattern of rail would not have been retained as a leading type if there had been no other reason; for it was found

that the lower face became so indented by the chairs on which the rail rested as to be unfit for an upper surface, unless the rail were turned over so frequently as to prevent such indentations. The inconvenience and expense of this turning proved so great, that the custom has been generally abandoned. But for roads laid on cross sleepers, the double-headed rail affords the great strength as a girder which is required, though there is no longer the same necessity for having the top and bottom of the rail precisely alike. One important point of difference between the doubled-headed rail and almost all other kinds is that the former requires iron chairs; and the trade in railway chairs would be almost at an end if this form of rail were discarded.

Turned rails.

No longer used.

Chairs required.

See CHAIRS, *page* 246.

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Vignoles or flange rail.

The *Vignoles* or *flange* rail is suited either for longitudinal or cross sleepers, and it has a sufficiently stable base without chairs, and especially so when a continuous bearing is provided on longitudinal sleepers. When the rail is fixed on wooden cross sleepers, although there is sufficient strength and stability, yet under heavy traffic the weight concentrated on the occasional supports tends to press the rail into the wood, the flange not affording the same wide solid base as an iron chair. The pressure is apt in time to destroy the sleeper, unless great care has been used in bedding the rail truly upon it, or by interposing a base-plate of wrought-iron wider than the rail. Flange rails are fastened to the sleeper by bolts which may either pass through a hole in the flange, or may grip the edge of the flange; and there are many varieties of such bolts. Flange rails are so extensively used abroad that, if English railways be left out of the question, a greater number and weight of them are made than of all other kinds put together.

How laid.

Fastenings.

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Bridge rail.

The *Bridge* rail has been preferred by some engineers as being more symmetrical, and as having its wearing parts better supported than, as in a flange rail, by a single web. Bridge rails need longitudinal sleepers, this being the plan adopted on the Great Western Railway in England, where this form of rail was first introduced by Brunel for the 7-ft. gauge. Having thus a continuous support, much less strength is needed in the rail than where it has to span, as a girder, between cross sleepers; consequently, bridge rails, even for heavy traffic, are usually only about two-thirds the depth and weight of double-head or flange rails. Bridge rails are spiked down to the sleepers, and at the junction of two rails they are connected by a base plate, which covers the joint. Such a connection is however inferior

As on G. W. Ry.

See SLEEPERS, *page* 248.

How laid.

Jointing. to the fishing-joint of flange or double-head rails, and needs constant attention, not only, as on all kinds of permanent-way, by adjusting the ballast, but by wedging and packing between the rail and the sleeper. **Light rails.** Bridge rails of small light section were formerly much used for tramways in and about mines, but they have been gradually superseded by flange rails. There is rather more labour in the production of bridge rails than of other kinds, and they are generally a few shillings per ton dearer. **Old rails.** Old iron rails of bridge form are considered more valuable as material for reworking than other kinds.

Barlow rail. The *Barlow* rail, which may be considered as a development of the bridge rail, was at one time extensively used. Its wide base gives stability not only to the rail itself but to the whole permanent-way, and it is more independent of sleeper supports than any other kind. Indeed, it has in some instances been laid directly on the ballast to form rail and sleeper in one, although generally it is laid on longitudinal timbers. **Disadvantages.** But when laid directly on the ballast it needs constant adjustment, and this circumstance, as well as certain inconveniences in regard to points and crossings, and also in the manufacture of the rail, led to its abandonment, and although still made in small quantities for special purposes, it is seldom employed on railways. It has been used on some railways as a cross-sleeper; piles have been made by riveting two rails together, flange to flange; and as the upper flange-plate of a box-girder, it forms an effective beam for a travelling crane.


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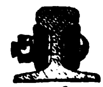
The two greatest improvements which have been introduced in connection with rails since railways were established, are the fishing-joint, and the use of steel instead of iron. It is hardly necessary to state how immensely the fishing-plates add to the strength of a rail-joint, and to the stability of the permanent-way. It is attempted in the case of the double-headed rail to still further strengthen the joint by carrying the fishing beneath the rail, the increased strength being obtained not by an actual grip at the under part of the rail, but by the greater depth thus given to the fishing-plate. Double-headed rails, with the lower bulb smaller than the upper, and known sometimes as "bull-head" rails are convenient for this method of jointing; but the flange rail is also sometimes so jointed, the fishing-plate coming down to the edges of the flange and even below them. Fishing-plates must be made to suit the form of the rail very exactly.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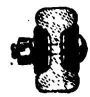
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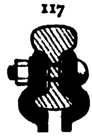


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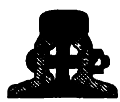
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The Bessemer inventions by which iron is converted into steel rapidly, cheaply, and in large quantities, without the elaborate pro-

Bessemer rails. *See page 150.*

cesses previously necessary, have had their principal application and success in rails. The later inventions of Siemens and others have tended to still further reduce the price by cheapening the production and by maintaining a competition favourable to the consumer. Indeed, the introduction of steel rails has subjected the whole trade to a change unparalleled probably in any other branch of industry; new standards of excellence have been inaugurated and, with them, new conditions of purchase. The methods of manufacture are really simpler and cheaper for steel than for iron; and unless some hitherto unknown defects be found in steel, or some new and cheaper method of making iron discovered, iron rails may be considered as superseded. The advantages which steel has over iron for rails are various. The steel rail has greater strength as a girder; it offers greater resistance to crushing; and its surface will endure abrasion longer. Steel rails not only wear out more slowly but more evenly than those of wrought iron; the latter, being composed of numerous pieces of iron "piled" together, and imperfectly welded in the process of rolling, laminate, and the lurching of heavy engines shears long flakes off the heads; while steel, being homogeneous, only yields to traffic by the uniform abrasion of each particle. Those steel rails wear out quickest which are most subject to the influence of sand and skidded wheels. The less frequent expenditure in relaying steel rails, and the fewer interruptions by platelayers to passing trains, especially at station sidings and junctions where the traffic is great, are advantages which are now universally acknowledged.

Trade in rails altered.

Iron rails superseded. *See page 141.*

Advantages of steel. *See page 150.*

Homogeneity.

Durability.

Less frequent re-laying.

Steel weakened by holing and notching. *See page 152.*

As has been already described, steel will not bear the operation of hole-punching without injury; the holes must therefore be drilled; and even drilled holes weaken a steel rail more than an iron rail. Even the notching of the flange for the spike weakens the rail, and such notches should be made only at the ends, or avoided altogether in the rail, and made in the fishing-plate when it projects enough to allow it.

Standard patterns. *See page 140.*

Not yet established.

It is generally expedient to adopt some existing pattern of rail, especially if the quantity required be too small to justify the cost of new rolls, and the pattern-books of manufacturers allow of ample choice. It would be a great advantage if standard patterns could be agreed upon by railway engineers, as makers could then roll rails and store them for sale afterwards, which, without established standards, they cannot venture to do. Several engineers have designed so-called standard patterns, but until these are generally recognised and accepted, the word is evidently a misnomer.

Rails made stronger than formerly.

Usual weight of rails.

Of steel rails.

Weight in United States.

On the important European lines the use of heavy engines and higher speeds have rendered necessary stronger and heavier rails than formerly; for although some very heavy patterns were tried on the earlier railways, rails of only 60 lbs. to the yard were common in England in 1860, while rails of 80 and 85, and even 90 lbs. have since become usual. Nor has the introduction of steel caused any reduction in the size of rails; it is found that the weight affords stability to the road and a steadiness to the trains which would otherwise be unattainable. But the distance between the cross-sleepers may be safely increased by the use of heavy steel rails. In other European countries, flange rails seldom (1880) exceed 72 lbs., while in the United States, a range of from 50 lbs. to 65 lbs. includes the various sizes used on standard-gauge railways. The use of fishing-plates also encourages the preference for heavy rails, because the space needed for the plate and bolt-holes is inconveniently circumscribed in small rails.

Light rails for little railways.

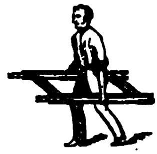
See page 63, Part I.

Contractors' rails.

For little railways of 2 ft. to 3 ft. gauge, rails of from 15 to 30 lbs. are used; and for narrow-gauge railways of from 3 ft. to 3 ft. 6 in. gauge, with rolling-stock of moderate weight, rails weighing from 30 to 50 lbs. per yard are sufficient. Contractors' rails for temporary use are made of all weights, from 10 to 40 lbs. per yard. The price of light rails under 40 lbs. per yard is from 5s. to 20s. per ton more than the price of the heavier sections.

Portable railways.

Where used.



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Weight of rails.

Cost of little railways.

See page 304, WAGONS.

Light steel rails may be so framed together with sleepers and ties in lengths of from 12 to 15 ft., as to form a portable railway, which may be readily laid down or removed by unskilled workmen. These railways are very useful for manufactories, brick-fields, farms, plantations, and mines. By the use of small wagons, weighing, when loaded, not more than two tons, rails of 10 lbs. per yard are sufficient for railways of 18-in. gauge; and for 2-ft. gauge, rails of 15 lbs. per yard are sufficient for the safe passage of locomotives weighing four tons, and capable of hauling 50 tons on a level. Railways, as above described, cost from £300 to £600 per mile, inclusive of switches, crossings, turn-tables, and wagons, according to the exact weight of the rails and current prices of materials. If the capital outlay can be afforded, the higher price is the cheapest in the permanent advantages it affords.

Sale of rails by weight.

Rails are sold by weight, and in England by the ton of 20 cwt. Iron rails cost about the same as the cheapest bar-iron. Steel rails (1880) from £1 to £2 per ton more. Fishing-plates cost from £1

Cost of fastenings. to £2 per ton more than the rails; fishing-bolts £10 more; and spikes from £6 to £8 more: but sometimes both rails and accessories are included in one average price. This average is generally from 5s. to 15s. per ton above that of the price for rails alone. Light rails are generally made in shorter pieces than heavy rails; more fishing-plates are consequently required, and the proportionate weight of plates and fastenings to that of the rails is greater.

Average price for rails and accessories.

Countries where rails are made.

The principal countries other than England where iron and steel rails are made are (1880) Belgium, France, Germany, Austria, and the United States. But although the rolling-mills that have been established in these countries have necessarily supplied many of the rails that would otherwise have been made in England, the effect which such competition will have in what are considered neutral countries, is greatly limited; for in none of these countries can rails be made so cheaply as in England. It is only the protection afforded by customs duties on imported rails, and the artificial prices thus ensured, and the demand for rails in the vicinity of the manufactory, that have induced capitalists to establish rail-mills in places where the conditions of production are less favourable than in England.

Rails made cheapest in England.

See PROTECTION, *pages 38 and 52.*

Purchase of rails.

Simple as the definition of a rail would appear to be, a bargain for rails is an example of the importance of purchasers affording full information of their wants. If a manufacturer be merely asked the price of a certain quantity of rails of a certain section, and especially when, as is often the case, such an inquiry comes from abroad, no satisfactory answer can be given without a full specification of the conditions. The absence of such a specification disinclines manufacturers from paying serious attention to the inquiry, and vague statements of price are alone obtained, unless, with full particulars of the service required, the decision as to the form of rail be left to an engineer, or to the manufacturer, who should then be asked, on his part, to furnish a specification. The points which determine the price, and on which information should be furnished, are as follows:—

See page 48.

Full specification required.

Particulars which determine price.

See page 11.

Shape and weight.

1. *The section of rail required and the weight per yard.*

2. *The limits of difference in weight* above and below that specified within which the rails will be received. A margin of 2 per cent. on single rails and 1 per cent. on the total quantity are usual limits.

Length.

3. *The length of the rails* and the degree of accuracy in this respect which is demanded. For rails of 40 lbs. per yard and upwards, 24 ft. is an ordinary length, while for rails of from 10 lbs. to 40 lbs. a yard, a length of 18 ft. to 20 ft. is more usual; and a difference of about ¼ in.

over or under the specified dimension is usually allowed. In rolling rails, a certain number are found to be short or defective at the ends; and in such a case it is economical to cut them to shorter lengths rather than to waste the labour already bestowed on them. It is usual for the purchaser to accept these shorter lengths, if of certain specified dimensions, and if they do not in the aggregate exceed 10 per cent. of the whole quantity. Where such a concession is not made to the exigencies of manufacture, an extra price of from 5s. to 10s. per ton would have to be paid for the rails of standard length, to recoup the maker for the short rails which are wasted.

Degree of accuracy.

Short lengths allowed.

4. *The tests which the rails must satisfy.* The quality of rails is ascertained by testing a certain number with blows from a steam-hammer, and bending and breaking them by a falling weight. Very often the process of manufacture is also specified, but although the purchaser may naturally require a certain quality (and in iron rails even a peculiar arrangement of material), it is obviously unfair to bind the manufacturer to exact processes and to make him responsible for results also. The latter is the more important condition to enforce. Sometimes a guarantee of durability for a term of years is demanded; but manufacturers before agreeing to such a condition require full and trustworthy information as to the kind and amount of traffic.

Tests of quality.

Methods of manufacture prescribed.

Guarantees of durability.

5. *The kinds and quantities of fishing-plates, bolts, spikes, or other accessories which are required.* Great care is necessary in arranging the holes in the rail to suit the fishing-plates and to ensure the proper position and jointing of the rails when laid in place, and these points should be exactly specified. Due accordance of the holes, plates, and bolts having been arrived at, uniformity is maintained by working to templates and applying gauges to every rail. Surplus fastenings are generally provided; 5 per cent. extra fishing-plates and 10 per cent. extra bolts and spikes being usual quantities.

Kind and quantities of fastenings.

Templates and gauges.

Surplus fastenings.

6. *The place and periods of delivery.* The expenses of transport bear a considerable proportion to the total cost of rails exported, and it is to the purchaser's advantage in inviting tenders to give the option of several shipping ports, so as to suit the localities of the different manufacturers.

Place and time of delivery.

See EXPORT, *page 37.*

Some or all of the foregoing conditions may be left to the discretion of the engineer or agent who purchases the rails, or even to that of the manufacturer; but it is then necessary that they should be acquainted with the circumstances, viz.—

Latitude in choice of rails allowed.

Particulars on which rails can be designed.

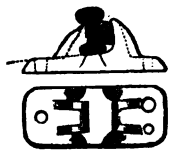
See LOCOMOTIVES, *page* 273.

Effect of sand and skidded wheels.

Established patterns and rules.

The gauge of the railway; the kind and quality of the permanent-way and ballast; the kind and arrangement of the sleepers (or free scope to design these also); the radius and frequency of the sharpest curves; the kind of locomotives in use, their weight when loaded, the length of rigid wheel-base on which the load is distributed and the maximum weight imposed by any one pair of wheels; the section of the wheel tires to which the head of the rail must conform; the probability of sand being frequently used (for the use of sand on slippery rails on steep inclines, and the skidding of the wheels, rapidly wears out the rails); the nature and probable amount of traffic per day which is expected to pass over the rails, and at what speed. Of course, where the rails are for a railway where patterns, rules, and conditions have been established and are well known, it may be sufficient, when making a bargain to stipulate for the usual pattern and the usual conditions; but these conditions, even if well known, should be recited in each case before an absolute contract is made.

Chairs.



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Large quantities used in England.

Machine moulding.

Chairs are required principally for double-headed rails which lie on cross-sleepers, but as this form of rail is not largely used except in England, the quantity of chairs exported is small in proportion to that of rails. But the quantity used in England is so large that great economies in manufacture are rendered possible. Special machinery is used for moulding the chairs, and by this means a much larger tonnage can be produced in a given time by a certain number of men than is possible with other castings, even of a simpler form, made by hand; and the cost of production is proportionately low. There are several foundries in England producing more than 1,000 tons of chairs weekly.

Price of chairs.

See page 33.

Weight.

Chairs heavier than formerly.

The selling price of chairs ranges from £1 to £3 above that current for pig-iron, so that when pig-iron is at £3, ordinary chairs can be purchased for from £4 to £6. Chairs are made of size and weight according to the size of the rails, the distance apart of the sleepers, and the weight and speed of the engines. On English railways of the standard-gauge, sleepers are generally placed from 28 in. to 39 in. apart, and the chairs weigh from 25 to 50 lbs. each. Locomotives are heavier than in the earlier days of railways, and a larger bearing surface than formerly is needed for the rail. It is on the main lines of railway, exposed to constant and heavy traffic, that chairs weighing more than 35 lbs. are used. Chairs are seldom used for flange rails, as these are held down to the sleepers by

spikes, fang-bolts, or clips; and chairs are still less necessary for bridge-rails laid on longitudinal sleepers. In buying railway chairs it is usual to specify certain tests by which the quality of the iron may be ascertained, the test being generally that of loading sample beams or bars of iron.

Tests of quality.

See TEST-BAR *page 133.*

Chairs fastened to sleepers.

Chairs are fixed to wooden sleepers by iron spikes or wooden trenails, or by both. Iron spikes by themselves are not effective, as the tremor caused by the passing of trains loosens the spike and causes it to rise above the chair. Trenails are about 6 in. long, made of heart-of-oak, and are turned in the lathe to a diameter of about $1\frac{5}{16}$ in., and then squeezed by hydraulic pressure to a diameter of $1\frac{1}{8}$ in. The trenails fit tightly into holes in the chairs through which they are driven into the sleeper; and the lower part in the sleeper swells, when exposed to wet, into its original diameter, so that it cannot come out; but in the course of time it is liable to rot and break off at the neck or shoulder below the chair. On the principal English railways where this system of fastening is adopted, two or even three trenails and an iron spike are used for each chair. It has been attempted to combine the advantages of the two kinds of fastenings by using a wooden trenail with an iron spike within it, but this has not been widely adopted. Trenails cost about £4 per thousand. Iron spikes cost from £2 to £3 per thousand, or from £4 to £6 per ton above the current price for ordinary bar-iron. The rails are held in the chairs by wooden keys or wedges, which act as a cushion to deaden the percussion of the passing trains, and which can be driven in and tightened from time to time as they shake loose. The keys are generally made of fir-wood compressed, and those of a size suitable for a standard-gauge railway cost about £5 per thousand (fir), £7 (elm), and £8 (oak). Various kinds of metallic wedges have been tried, but except in hot countries (where spiral wrought-iron keys have been found suitable) nothing has proved so effectual as wood for double-headed rails held in cast-iron chairs.

Trenails.

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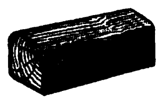
Iron spikes.

Cost of trenails and spikes.

Wooden wedges or keys.



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Price of wooden wedges.

Metallic wedges.

It is usual to furnish manufacturers with exact full-sized drawings of the chair required; and if a new pattern has to be designed, it must be based on the following *data*:—The section of the rail; the method of jointing the rail and the keying of the rail to the chair; the system of permanent-way adopted; the size of sleeper and the kind of wood; the distance of the sleepers apart; the maximum weight imposed on the rails by any pair of engine-wheels, and the speed of the trains.

New patterns of chairs, how designed.

Sleepers. Usually of wood. Prices.

The *Sleepers* used on English railways are almost invariably made of wood either of a rectangular or half-round section; the timber being creosoted or otherwise saturated with a preservative material, to prevent decay. The price depends mainly on the proximity of suitable growing timber, or the price at the nearest port where timber ships arrive; Baltic red wood (fir or pine) being the kind generally imported. In England from 5d. to 8d. per cubic foot is the range of price for half-round cross sleepers, and from 8d. to 12d. for rectangular sleepers. Half-round sleepers are generally 10 in. wide, 5 in. deep, and cost therefore from 15d. to 24d. each. Their use is confined almost entirely to narrow-gauge railways, or temporary lines such as contractors use. Rectangular sleepers for standard-gauge railways are generally 9 ft. long, 10 in. wide, and 5 in. deep, and cost therefore from 2s. to 3s. each, to which must be added from 8d. to 1s. for creosoting. For lines of mètre gauge or those of 3 ft. 6 in., rectangular sleepers, 9 in. by 4½ in., will suffice; and for little railways of 2 ft. and 2 ft. 6 in. gauge, rectangular sleepers 7 in. by 2½ in.; the prices for these smaller sizes being not only less, but less per cubic foot, because they can be sawn from smaller and less valuable timber. On standard-gauge railways the sleepers are generally laid about 3 ft. apart; from 1,800 to 2,000 sleepers being required for each mile of single line; but on narrow-gauge railways laid with light rails, the sleepers should be nearer together, 2,400 per mile being about the number required. Longitudinal sleepers are preferred by some engineers as affording a continuous and stable road, and as allowing lighter rails than when cross sleepers are used; but the general opinion is against this system. Such sleepers are usually 12 in. wide and 6 in. deep, but on the Great Western Railway in England, longitudinal sleepers 14 in. by 7 in. are used for supporting bridge rails; these larger sizes costing (creosoted) 2s. per cubic foot, or about 15d. per lineal foot at a time when the former cost 18d. per cubic foot or 9d. per lineal foot.

Half-round sleepers for small lines. Rectangular sleepers. For standard gauge. For little railways. *See page 243.* Distance apart of sleepers. Longitudinal sleepers. As used on G. W. Ry. *See page 240.* Cost.

In constructing railways in any country, the presence or absence of timber suitable for sleepers is one of the many local circumstances which determine the cost of the line. Large quantities of sleepers are imported into England from the Baltic timber districts, and, after having been creosoted or otherwise treated, are re-exported to colonial or foreign railways; and only rarely are the sleepers sent direct from the timber countries to their final destination. Difficulty arises sometimes in the shipment of sleepers because of the delete-

Indigenous timber for sleepers. *See page 70, Part I.* Baltic timber. Export.

rious effect which creosote has on other cargo; and it may become necessary or expedient to charter vessels expressly, or to take advantage of vessels carrying coal, iron, or other rough cargo.

Creosoted timber deleterious as cargo.

In many countries where there is no indigenous timber, or where the climate or the soil is unsuited to timber, the question arises whether iron sleepers may not be preferable, and in parts of India and other tropical countries, the ravages of ants are so destructive of timber that iron has had to be substituted. Yet the prediction confidently made by engineers when railways were first introduced into India, as to the impossibility of using timber sleepers in any of the railways there, has not been wholly justified by later experience. Creosoted wooden sleepers continue to be imported into tropical countries, and in some cases indigenous timber is used; but the latter is generally harder than fir, and more difficult to work, and it is necessary to bore the holes for the spikes. On railways under English control in non-tropical countries, timber is still generally preferred, but iron and steel are largely used in foreign countries; and it may be expected that the use of metallic sleepers will increase as the growing needs of railways and the lessening supply of timber tend to raise the cost of the latter.

Climate and ants destructive of timber.

Hard wood for sleepers.

Iron and steel sleepers.

Much ingenuity has been directed towards the contrivance of substitutes for timber sleepers; and the interests at stake are so large, and improvements, if effected, would be adopted on so wide a scale, that invention has been stimulated to a more than usual degree. Not only have various systems of permanent-way been contrived, but each one that has found favour, or has appeared likely to succeed, has been seized upon by other inventors, who have altered, modified, or improved the invention sufficiently to justify a claim for a new patent. Since 1850 probably scores of thousands of pounds have been expended, and, to a great extent, wasted by inventors, manufacturers, and others in experiments connected with iron sleepers. A leading type amongst such inventions is Greaves' "pot" sleeper, which not only has proved useful and successful, but has served as a starting-point for a variety of similar contrivances. This pot sleeper is of cast-iron, is circular, and in form is like an inverted bowl or saucer, the rail resting on the convex side against a chair or bracket cast upon it, the sleeper and chair being thus combined in one piece. These sleepers weigh about 80 lbs. each for standard gauge or 5 ft. gauge railways, and cost from 10s. to 15s. per ton more than the current price of ordinary chairs. On standard-gauge lines these sleepers

Numerous inventions.

New forms of permanent-way.

Money spent by inventors.

Greaves' pot sleeper.

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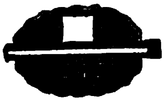
Weight and price. *See page 246,* CHAIRS.

How laid. are placed about 3 ft. 6 in. apart under the centre of each line of rail, and are tied across the track by wrought-iron bars. A hole in the casting allows the plate-layers to ram up or adjust the ballast below the sleeper. **Oval sleepers.** Several modifications of this sleeper have been made; an oval shape with two or three attachments instead of the one on the circular casting, being their chief characteristic; while in some the convex bowl is made of a corrugated or undulating shape. The oval or elongated castings weigh about 100 lbs. each.



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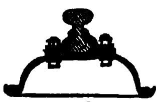
Railway engineers on the Continent have done more than English engineers in devising substitutes for wooden sleepers, and have generally preferred wrought-iron or steel to cast-iron. **Wrought-iron and steel sleepers.** The greater weight of cast-iron is an advantage after the track is laid, but the weight and liability to fracture are disadvantages for transport. **Compared with cast-iron.** Cast-iron is more durable against rust than wrought-iron or steel, and its greater thickness can better afford wasting by rust. On the other hand, cast-iron is the less elastic material, and is unsuitable for laying on a hard road. **Variety in shape.** Some wrought-iron sleepers are of the bowl type, round or oval, smooth or corrugated, and are made by being pressed in dies while hot. Some are rectangular, and are of the self-contained buckled-plate arch form. There is a much greater variety than in cast-iron, although the scope of the designer is more limited by the exigencies of manufacture. Everything connected with the permanent-way of a railway is wanted in such considerable quantities that the relative cost of different systems goes far to determine choice. To this end, a shape which can be made in a rolling-mill has been the aim of some designers. **Trough-shaped sleepers.** *See page 150.* Instead of the bowl form, which needs to be pressed in a die, a trough form, which can be rolled like a channel-bar, has been successfully adopted. Laid with its open side downwards, some engineers use it as a longitudinal support for the rail, and others as a cross-sleeper. **Thickness and weight.** Wrought-iron sleepers have been generally made about $\frac{1}{4}$ in. thick, and being about one-third the weight of cast-iron sleepers, and costing less than three times as much per ton, the expense is rather less, and much less in regard to carriage. **Steel sleepers.** When steel is substituted, it is generally made about one-fourth part thinner than wrought-iron, but the cost is about the same.



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Modes of fastening. There is as much variety in the modes of attaching the rail as in the sleeper. **Bolts, keys, clips.** Bolts, cotters, and clips of different kinds have been designed, but the simplest are generally found to be the best as well as cheapest. The fastenings are mostly of wrought-iron, occasionally

of steel; but where these, because of their shape, would cost more than 3d. per lb., malleable cast-iron annealed is sometimes substituted. Most iron sleepers are, as above described, adapted to rails of ordinary kind, but in some cases, instead merely of a modification of the sleeper, the whole permanent-way is modified, and rails have been specially contrived like single bulb-iron, without a flange or other protuberance at the bottom, so that they can lie between two iron supports, which together form a longitudinal sleeper.

See page 154.

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Choice of sleepers, how determined.

To allow a proper choice of sleepers, the following information is necessary :—

Rail and gauge.

1. The section of the rail, the gauge of the railway, and the gauge of the "six-foot" (*entre-voie*).

Ballast.

2. The kind of ballast and thickness of ballast available or proposed.

Weight and speed of locomotive: *See Chap. XXII.*

3. The kind and weight of the locomotives and rolling-stock, with the maximum weight on one pair of wheels, and the speed of the trains.

Climate.

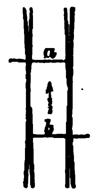
4. The climate, not only in regard to extremes of temperature, but also as to the rainfall, and its effect on the permanent-way.

Available timber.

5. Information concerning the kind and cost of indigenous timber.

Switches and points.

Switches, or points (*rails mobiles*), are made of iron or steel, and as the extra cost of steel bears but a slight proportion to the whole price, it is generally preferred. Great ingenuity has been exercised in connection with switches, and modern invention has reduced to a minimum the risks that must always attend the passage of trains through the points, especially facing-points. The risk is obviously much greater at facing points *a* than at trailing points *b*, and therefore the former are avoided as much as possible on main roads, the trains having therefore to back when passing on to a siding. This plan, however, involves delay in shunting. Owing to the great variety of rails used on different railways, switches necessarily vary also in their details. From £16 to £20 is the range of prices for different kinds of switches made of iron (including rods, levers, and boxes), and from £18 to £25 when made of steel. Very often, rails of the kind used on the railway are supplied to the manufacturer, who, having the cost of the material thus saved to him, makes the rails up into switches at about two-thirds of the above prices.



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Facing and trailing points.

Cost of switches.

These prices are for standard-gauge railways; for narrow-gauge lines, with rails not exceeding 40 lbs. per yard, the prices are only

Particulars for designing switches.

about three-fourths of those stated above. To enable a manufacturer to supply suitable switches, he should be informed of the section of the rail and the system of permanent-way; the gauge of the railway and that of the six-foot; the radius of the turn-out; and whether the railway is to be a durable one for busy traffic or merely for temporary or infrequent use.

Crossings.

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Angle 1 in 5.

Chilled cast-iron or steel.

Crossings are made either of steel rails or of solid cast-steel or of cast-iron "chilled" by being cast in iron moulds, which process, by cooling the metal quickly, gives an intensely hard face. Chilled-iron crossings are more durable than any kind of steel, and for situations of minor importance or for slow-speed traffic are best as well as cheapest. For fast-running trains however, where steel rails are used, crossings made of steel rails are preferable, as they have the important advantage of being similar in regard to strength and elasticity to the rest of the road. This circumstance outweighs the greater durability afforded by the more rigid chilled-iron crossing.

Varieties of crossings.

Prices.

As is the case with switches, there are many varieties of crossings, the choice depending mainly on the gauge, the weight and section of the rails, the nature of the traffic, and the position of the crossing in relation to the main roads. On these circumstances, and on the accessories which are required, such as check-rails or special chairs, the price also depends; but a range of from £10 to £15 includes almost every kind. The angle should not be finer than 1 in 10, nor coarser than 1 in 5. For light rails, or for temporary or contractors' purposes, a set of points, including switch and crossing complete, costs about £16. Where a siding crosses a main road without connecting with it, what is known as a "diamond crossing" is used. If the lines cross at too sharp an angle there is a risk of the train wheels leaving the proper track, especially if the train has to be started when on the crossing. The angle should not be sharper than 1 in 6½ when there is full scope for choice; and the regulations of some railways forbid a sharper angle than 1 in 8, although an angle even of 1 in 12 is sometimes ventured on. Engineers and others should, in purchasing crossings, specify clearly what they wish to include, because the term has different significations. Thus, by a railway engineer or contractor, a crossing is often intended to mean the entire material for crossing from one line to another, and not only includes the switch and crossing pieces, but the rails that join one line of rails to the other. And even more than this is sometimes included where a "cross-over road" crosses several lines of railways.

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Angle 1 in 2½.

Diamond crossings.

But by a maker of such things, a crossing means, if not otherwise specified, only the actual crossing-piece. In such cases, therefore, it is necessary not only to state the gauge of the railway, the gauge of the "six-foot," and the section of the rail, but to furnish a sketch showing the position of the lines of railway which are to be joined and the angle of the roads.

Turn-tables.

Turn-tables have been in use from the earliest days of railways, both for engines and carriages, but for the latter purpose they are not used so often as formerly, as they occupy much space, and are an obstruction on the permanent-way. They have been superseded in many situations by traversers. The earlier turn-tables for locomotives required elaborate racks, winches, or other gear for turning them, a process occupying five or more minutes. Now, by balancing the turn-table carefully, it can be easily pushed round by one or two men in half a minute. The diameter of a balanced turn-table of this sort must be from 3 to 6 ft. greater than the length of the wheel-base of the engine and tender, because the centre of the wheel-base seldom coincides with the centre of gravity of the engine; the latter varying also according to the quantity of water and fuel in the tender. In order that the turn-table may revolve freely, there should be no pressure on its outer wheels (which serve only to sustain such portion of the weight as may be unbalanced), but all the weight should be borne by the centre pivot. An experienced engine-driver will accomplish this by bringing his engine to a standstill at such a point that the centre of gravity shall be exactly over the centre pivot; and the turn-table, with the load thus adjusted, is easily pushed round.

Less used than formerly.

Engine turn-tables.

See VIGNETTE, *page* 239.

How balanced.

The great length and weight of a modern locomotive with its tender have rendered necessary larger and stronger turn-tables than formerly, and instead of 40 ft. maximum diameter, 42 ft. and 45 ft. are (1880) often required. In the United States, turn-tables from 50 to 60 ft. diameter are made to suit the long engines and tenders in use there. It is very important that a turn-table be of great strength, so that it may not deflect under the load (a modern engine and tender equipped for service weigh upwards of 60 tons), well fitted so that it balances and moves easily, and that the central pivot and its bearing be properly hardened.

Diameter.

Large turn-tables in United States.

See Chap. XXII., LOCOMOTIVES.

A locomotive turn-table 40 ft. in diameter of the best modern construction, and inclusive of the iron-work beneath it, costs from £350 to £400, or if covered with a floor of iron plates, from £400 to £500.

Cost of turn-table.

Depends on size. For turn-tables of greater or less diameter than 40 ft. an addition or deduction of about £10 per foot of diameter should be made. To the above prices must be added the cost of excavating and lining the circular pit in which the turn-table revolves, and of building the **Foundations.** foundations of masonry or brickwork on which the iron pivot and rails will rest. If only one siding passes over the turntable the circular wall need only be built where the sidings come. Sometimes, for small turn-tables, the circular lining is iron instead of brickwork. Centre-balance turn-tables should be fitted with relieving apparatus at the ends, so arranged as to wedge up the table to the outer bearings to give it stability and steadiness there while the engine is entering or leaving it.

Carriage turn-tables. Turn-tables for carriages and trucks are made from 12 to 20 feet diameter, and for those made of iron the prices range from £7 to **Prices.** £11 per foot of diameter, the higher rate including the cost of iron plates on the top, instead of the wooden floor which is often used, **Small turn-table.** but which is liable to ignition from the locomotive. Small turn-tables 6 ft. diameter, cost from £25 to £30 if wholly of iron, and such turn-tables are useful on wharfs and landing-jetties. Small iron turn- *See page 243.* tables for railways of from 1 ft. 6 in., to 2 ft. 6 in. gauge, such as are used at mines and quarries, cost £5 to £15.

Carriages are seldom turned for the mere purpose of reversing their position in a train; but many station yards are so arranged that a partial turning of the carriage is necessary for the marshalling and arranging of trains. Turn-tables are generally placed on sidings, and they should not be placed on main lines, or where running trains may have to pass over them.

Traversers. *Traversers*, by which engines or carriages can be transferred from one line of rails to another across the station or station yard, are made **Where used.** of a length to suit the rolling-stock. Engine traversers are rarely used except in repairing-shops, where they sometimes afford a con- **Engine traversers.** venient means of bringing an engine into or out of the shop, and in **How propelled.** such cases they are propelled either by a small engine fixed upon the *See page 112.* traverser, or a quick-running cotton, hempen, or wire rope, worked by an adjacent fixed engine. Carriage traversers are made from 12 ft. to 18 ft. long, for although carriages measure (including the buffers) **Carriage traversers.** from 22 to 30 ft. the traverser need be but little longer than the wheel-base. Traversers are principally needed where space is limited for shunting, and they are seldom required where space is ample **Prices.** and the traffic is small. Engine traversers cost from £400 to £600,

and about £200 more if a propelling engine is added. Carriage traversers cost about £100.

The choice or design of a turn-table or traverser depends on the following points, concerning which full information is necessary: The gauge of the railway and that of the six-foot; the section of the rails; the dimensions and weight of the engines or carriages, and the weight on each pair of wheels. If for engines, a longitudinal and cross view should be furnished, showing the extreme projecting parts, such as the coupling-rods, cylinder-cocks, and cattle-guards. If for carriages, the shape and dimensions should be indicated by a profile showing such projections as foot-boards and steps. It is needful also to furnish a sketch of the site on which the turn-table or traverser is to be fixed, indicating adjoining lines of rails. The addition of a propelling-engine is determined partly by the cost of hand-labour and of fuel.

Choice or design, how determined.

By weight and size of engines and carriages.

See page 287.

Signals of a very simple kind were used in the earlier days of European railways, and the subject demanded and received but slight attention. This is still the case on many foreign railways where the traffic is small, but on the principal European lines, especially those in England, the multiplication of junctions and crossings, the vast increase of traffic, and the running of quick passenger-trains and slow goods-trains on the same line, have rendered elaborate precautions necessary for safety. The most notable changes in signals in recent times have been connected with the "block system," which may be briefly described as the enforcement of an absolute distance, or space of rails, between trains following each other on the same line, instead of the mere interval of time which used to be relied upon, and which was the cause of many accidents. Signals being placed at intervals, generally ranging from a quarter of a mile in the vicinity of a station to two or three miles between stations, no train is allowed to pass one such signal till the preceding train is announced to have passed the next one in advance; the electric telegraph being, of course, essential to this system. The tendency of modern improvements has been towards automatic security, which may be defined as the prevention by mechanical means of the display of opposing signals which would involve or allow collision. By an ingenious system of "interlocking" the different levers, it is impossible to move any lever till all others—and with them the signals worked by them—are secured. This plan has been still further improved by bringing into the same interlocking system the levers working the points or

Signals.

Of simple kind for small traffic.

Elaborate signals in England.

Block system.

Described.

Automatic security.

Interlocking levers.

Signals and points connected.

switches, so that, except by a positive disregard of signals, no train can advance in a direction which will involve collision. The interlocking of levers and points and the electric block system have been also combined, attaining—though at considerable expense—a high

Facing-point lock.

See page 251.

degree of automatic perfection. Accidents having occurred through the imperfect closing of points for the passage of an approaching train, and through the altering of points before the whole of a train has passed, the points are now further protected by the addition to the apparatus of the "facing-point lock," which secures the proper closing of the points before a train can be signalled to approach, and prevents any moving of the points whilst a train is passing over them, no movement of the points being possible even by wilfulness or inadvertence on the part of the operator till the whole train has

Safe passage of quick trains through stations.

passed. The passage of trains through stations, or into sidings, or on to junctions, is thus made safe; and a quick succession of trains rendered possible. At some of the more important junctions and stations in England the number of levers in one signal-house is

Numerous levers in one signal house.

as great as 150, while groups of from 20 to 50 are very common. Each point or switch, and each signal, requires one lever (sometimes two points are connected with and worked by one lever), and the cost of the interlocking apparatus, exclusive of the cost of the signals them-

Cost.

selves or the switches, may be stated approximately at about £7 per lever; and including the cost of signals, connecting wires, or rods, house

Improvements in details.

and telegraphic apparatus complete, £25 to £35 per lever. Concurrently with the elaboration of signalling, improvements have been made in the mode of constructing the signals. Malleable cast-iron and steel have been substituted for certain parts formerly made of

See page 101.

cast-iron; and in the more important situations tubular rods have been adopted instead of wire for transmitting the power.

English system compulsory.

See pages 4 and 71, Part I.

These mechanisms are in England considered so essential to safe railway working as to be made compulsory by the Board of Trade authorities, whose sanction is necessary to the opening of new lines

Simple signals in foreign countries.

for passenger traffic. They are available for foreign countries when the traffic grows large enough to require it, but the simpler forms of single signals are still all that are required on railways where the traffic is small. The various discs, arms, semaphores, and other means of indicating *safety*, *caution*, and *danger* which were adopted independently on different railways, are rapidly giving way to the one simple kind of "semaphore," the universal adoption of one form of signal greatly adding to the simplicity of railway working.

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Semaphore.

Three signals are indicated: at night by lamps, red for "stop," green for "go cautiously," and white for "full speed;" and in daylight by semaphore arms at 90°, 45°, and *nil*, but on some railways the *nil* signal has been abolished, as it might be given by the action of the wind, and the two signals "stop" and "go on" are alone used.

Two signals only.

Stop and go on.

A semaphore post of wood 20 ft. high, with arms, lamps, and all appurtenances, costs from £16 to £20, which is increased to about £30 if the wire and extra gear necessary for working it as a distant signal be included. When required of a greater height than 20 ft., the price of the post increases by about 10s. per foot up to 40 ft. In countries where suitable timber is procurable, expense may be saved by importing only the ironwork and fittings. Posts of light iron framework are also used, and are very suitable for countries where timber is expensive, or for climates destructive of wood; they cost in England from 15 to 25 per cent. more than wooden posts.

Cost of signal posts.

Iron posts.

When it is desired, for a foreign railway, to obtain the advantage of the latest English inventions and experience in regard to the signal equipment of a junction or station, the following information should be furnished to the engineer or manufacturer to whom the choice, design or purchase is entrusted.

Arrangement of signals, how determined.

1. A plan of the station or junction showing the positions of the different lines and sidings, with a description of what each line is used for, the direction in which the traffic runs on each line being indicated by arrows; the curves on the approaches; and any objects which may interfere with the view of the signal by the driver of an advancing train, and which may render lofty signal-posts, repeating-signals, or special positions necessary.

Particulars enumerated.

Plan of railway at site.

2. An approximate description of the number and length of trains and the intervals of time between them; distinguishing through trains from those which stop or shunt. The probabilities as to future increase in the traffic should be stated.

Trains described.

3. The speeds at which the various trains pass through the station.

Speed.

4. The amount and nature of shunting and marshalling; the relative amounts of passenger, goods, and mineral traffic to be dealt with being stated.

Shunting.

5. The gradients for at least one mile on either side of the signals.

Gradients.

6. Whether the electric-telegraph is in use, or is intended to be used, for signalling between stations, or is available for the purposes of the railway.

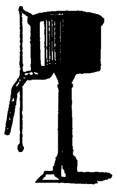
Use of telegraph.

Existing signals. 7. The kind of signals already in use on the railway or on the other lines with which it is likely to be connected.

Oil or gas lamps. 8. Whether gas or oil is available for the lamps, and if oil, its kind.

Climate. **Repairs.** *See page 264.* 9. The nature of the climate and the local circumstances affecting the transport of material, especially of long signal-posts; and the facilities for repairs.

Water-cranes. *Water-cranes*, and other apparatus for supplying the tank of a locomotive, depend for their arrangement mainly on the source from which the water is to be obtained and on the frequency and importance of the supply required. Thus, on a contractor's temporary railway, or where the minimum outlay is of importance, an ordinary hand-pump may be used to lift the water from a well or pond and deliver it into the engine-tank through a hose pipe, the latter being for convenience attached to a post. Such an apparatus would cost from £12 to £25. Even in England hand-pumping is often employed at small stations, but an elevated tank is always employed, so that though the pumping be slow, the engine can be quickly supplied from the tank. The latter may, for temporary service, be cheaply made of wood. If the tank be placed near the railway, a projecting pipe or swinging-jib can deliver the water to the engine. A circular tank for holding 1,000 gallons, and complete with supporting column, valves, and hose, would cost £90. Even where water-mains for railway or general purposes are sufficiently near to be utilised, a tank is necessary to ensure an immediate and abundant supply for the water-cranes. Sometimes the tank is at a considerable distance from the swinging-jib, and an iron column or stand-pipe is needed. If made with a swinging-jib, as a separate and self-contained structure, it is known as a water-crane. One of these, as above described, with valves complete, costs from £35 to £60, according to kind and quality; an additional cost of about £5 being incurred if a fire-grate or stove is attached for preventing the water from freezing in cold weather. Cast-iron tanks are generally preferred as being more durable and more easily put together than wrought-iron tanks, and except that the pieces are liable to damage in transit, are, in most respects, better than tanks of wrought-iron. A capacity of from 4,000 to 12,000 gallons is suitable for the purpose, but of course a larger tank is needed if the water-supply is intermittent and storage is necessary, or if the number of locomotives taking the water is great. At important stations, tanks



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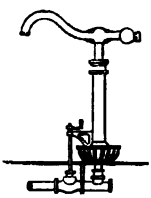
Tank required.



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Swinging-jib.

Cost.

Cast-iron and wrought-iron tanks.

See TANKS, *page 222.*

holding 100,000 gallons are provided. The apparatus should be at least equal to filling the largest tender in five minutes.

Water supply. **Hand-pumps.**

Where there is no independent source of water from which the tank or water-crane can be supplied, and where hand-pumping is not convenient or sufficient, a pumping-engine becomes necessary, and the cost depends primarily on the depth from which the water has to be lifted. When a pumping-engine is employed for this purpose, it is usual to make the tank large enough for supplying the station buildings and for general purposes. A pumping-engine complete, with boiler of the kind usual for this purpose, will cost from £80 to £500, according to the exigencies of the case. But at small stations, or where water is only needed in small quantities, the inconveniences of a steam-engine may be avoided by the use of a gas-engine, hot-air engine or other small motor. Locomotives may be rendered partly independent of water-cranes and tanks by having permanently attached to them an "elevator," which, by means of steam from the boiler, will draw up through a hose-pipe water from any contiguous well or pond. But the durability of the boiler depends greatly on the quality of the water, and there is a risk of impure water from a chance supply. The system has been adopted on some railways of a feed-trough laid between the rails and kept filled with water, which, as the engine advances, rushes up a shoot lowered from the tender. About half-a-mile of level track is essential to this method, which has been adopted both to obviate the necessity for stopping the trains and to procure a supply of better water than can be found near a stopping station.

Pumping-engines. *See Chap. X.* *See pages 191–6.* *See page 192.* *See page 212.* **Feed-troughs to supply trains while running.**

Elaborate arrangements are usual at large railway centres or important stations where the traffic is great. The supply of water is then arranged in conjunction with that of fuel, and a covered platform, with coal-stores, cranes, and water-jib, is specially arranged. A proper design for such a stage or platform depends on the following information, which should be supplied to those concerned:—

Fuel and water supply.

1. A plan of the site available, showing the lines and sidings and the approaches from the main line and adjoining station, with their gradients.

Arrangements, how determined.

2. The gauge of the railway and the kind of permanent-way.

3. The sources of the water-supply, with its pressure or levels in regard to the level of the rails.

4. The kind of fuel used and the quantity usually stored.

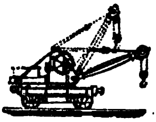
5. The number of engines to be supplied daily; the shape and length of engine and tender.

6. The capacity of engine or tender tanks and the maximum consumption of water per mile.

7. The extremes of temperature.

8. The kind of building materials available.

Break-down cranes.
See also Chap. XXV.



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Useful also for loading goods.

Prices.

Narrow-gauge cranes.
See CRANES.

Cranes cheapened if buffers and springs omitted.

"*Break-down*" *cranes*, as used for clearing a railway after an accident, are jib-cranes mounted on railway trucks. They are generally provided with a loaded box for a balance-weight, and the jib will lower down to allow the crane to pass under bridges; the jib as it is raised increasing in power as the radius it commands becomes less. These cranes are also useful for loading timber or other goods, and for this purpose can be sent to roadside stations which are not provided with cranes sufficiently powerful. Break-down cranes, completely equipped for lifting 5 tons, cost from £350 to £400 each; and for 10 tons, from £500 to £600 each. These prices are for cranes suited to the standard-gauge, and include the expense of screw-jacks, crowbars, clamps, and other usual accessories. For narrow-gauge railways a capacity of 4 tons and 8 tons respectively are more usual, at prices rather less than those just named, but such a narrow base does not of itself afford sufficient stability, and it is necessary to anchor the crane-carriage to the rails. As a considerable part of the cost is for the travelling-wagon, which must have buffers, springs, and usual appurtenances, like other rolling-stock, to render it safe when travelling as part of a train, cranes in other respects similar, but without springs and buffers, and furnished only with small wheels, can be purchased for about 20 per cent. less. Cranes so made are often used on landing-piers and in factories adjoining a railway. A break-down crane should be accompanied by a van or waggon carrying a vice-bench, chains, screw-jacks, tools, and lamps; and the tool-van and crane should always be kept in readiness, fully equipped, with lamps trimmed; and workmen appointed who should be at call whenever the crane is required.

Bridges.
See Chap. VII., Part I.

Road and railway bridges differ.

Bridges, either over or under railways, depend for their design and cost on the local circumstances of each case; and the points which determine the design have been already fully described. One main point of difference between a road bridge and a railway bridge is that while the former requires a strong floor to support a load over its entire surface, a railway bridge has its load confined to the rails, which can, if desired, be supported by a mere skeleton or framework

bridge. If, for the sake of cheapness, railway bridges are made in this way, there is the obvious disadvantage that, in case of the derailment of a train, the carriages are liable to fall through the bridge. A somewhat similar cheapness is obtained by the omission of parapets, a practice which is not favoured in Europe. It is difficult to keep the floor of a railway bridge water-tight, and in towns where bridges pass over streets this circumstance is often a cause of great inconvenience. The risk of leakage may be minimised by care in the design.

Frame bridges without floor.

Parapets omitted.

Water-tight floor.

The possibility of heavier locomotives being used on the railways at a future time should be considered when the bridges are designed. It is not so much the mere total weight as its distribution on the wheels which determines the effect on the bridge. Tank and other engines, in which a great weight is concentrated on a short wheel-base, impose very severe strains on the bridges over which they pass, especially on the cross girders. The engineer of the line and the locomotive engineer should be in accord concerning these matters.

Effect of heavy engines on bridges.

See page 129, Part I.

The kind of *Station Buildings* for passenger accommodation or for goods traffic depends so entirely on the particular circumstance of each railway and station that few general rules can be given. Where railways have to be made cheaply in a new country, or amid a sparse population, very simple structures may suffice at the commencement, if the funds are needed for more essential parts of the equipment. If the trains be few in number, waiting-sheds or huts, costing from £50 to £150 each, may suffice as roadside stations; the selling of tickets and transfer of luggage being entirely managed by the conductors who travel with the trains. And even where stations for passengers and goods have to be provided, buildings of a simple kind, quite unlike those usual on busy railways, may prove sufficient till the traffic has developed. Covered sheds for perishable goods, and facilities for loading and unloading vehicles conveying goods to or from the station, are among the first works which are necessary to the development of traffic. But though the outlay for stations may often be wisely limited or postponed till increasing traffic indicates the nature and extent of the buildings required, it is always advisable to secure ample land-space for stations hereafter, as the value of land, even if not needed for the purposes of a railway, almost always increases if near a station.

Station buildings.

Of simple kind for cheap railways.

Traffic managed by train conductor.

See page 289.

Covered sheds and cranes.

Ample land space should be secured.

See page 62.

The experience which has accumulated in regard to the most suitable forms of buildings in different climates is available to the

Variety of design depends on locality.

engineer who designs the railway, and who will generally endeavour to utilise the materials of the locality—though very often the iron-work and sometimes the entire structures have to be imported. Much of the local information which should be supplied to the engineer is described in other chapters. No rule can be given for the cost of station buildings, for not only the cost of the materials but the standards of excellence vary in different countries. In England, on the best railways, a certain comfort and completeness are required by law, and have to be given to all the rooms and offices connected with a station, so that even for village stations the cost will range from £400 to £800; and as traffic increases, the rules established by the government departments which regulate railways become more onerous. Such an outlay is seldom necessary on foreign railways.

See Chaps. XVI., XXVIII., and Chap. IV., Part I.

High standard of excellence on English railways.

Official rules.

See pages 4 and 71, Part I.

In parts of South America and other countries, where building materials are scarce, stations almost entirely of iron are imported from Europe. Such structures are generally composed of cast-iron columns united at the top by cast-iron spandrils or girders, on which rest a cornice and rain-gutters, the girder and gutter being sometimes combined in one casting. Upon the girders are placed wrought-iron framed roof trusses or principals, which are generally made of some span between 15 and 40 ft. The sides of the buildings are composed of sheets of corrugated iron, and the roof is covered with zinc, corrugated iron, or tiles laid upon wood boarding or iron laths. Wooden doors, glazed windows, and the necessary internal fittings are also generally imported. Greater finish and completeness may be given to the buildings by lining the sides, partitions, and roof with boarding. Sometimes, even where the station buildings are made entirely of local material, verandahs or sheds for covering the platforms are imported. Structures of this kind may be made very light, but in this respect the climate and the liability to strong winds have to be considered. In the case of iron buildings, there must of course be added the cost of transport, of levelling and draining the site, and the cost of erecting the structure.

Iron buildings.

See Chap. XXVIII.

How constructed.

Corrugated iron.

See page 145.

Wood lining and partitions.

Must be stable to resist wind.

Cost of transport and cost at site.

For terminal or other important stations, where imposing buildings and large-span roofs are required, great expense may be incurred. Owing to the great area enclosed by such buildings, their high cost as compared with smaller stations is not immediately apparent, if the cost per cubic foot be alone compared. The roofs of large span erected in England for important terminal stations have cost from five to eight shillings per superficial foot.

Large terminal stations.

To allow a proper design to be made for a railway station, information is required on the following points:— **Station designs how determined.**

1. A plan of the railway at the place where the station is required, showing the lines of rails, the sidings, junctions, and signals, the land available for buildings, and indicating the position, nearest the town or otherwise, most suitable for the offices; the length of the trains which stop at the station, and a cross-section of the rolling-stock, showing the height of the floor from the rails, and a profile of the steps, roof, and loading-gauge. **Plan of site.** **Length and shape of trains.** *See page 287.*

2. The rank which the station will occupy on the line, as first, second, or third rate—a definition which may be made according to the following circumstances: the size and population of the towns or villages adjacent to and making use of the station; the number of trains through, and the number stopping at the station, as indicated by a copy of the time-table. **Rank or importance of station.**

3. The approximate number of passengers arriving at or departing from the station, and the anticipated proportions of first, second, and third class; the number of railway servants who will be employed, and their grades, and whether living accommodation is required for the station-master or servants, and for how many; whether the passengers bring much luggage with them; whether parcel traffic is to be provided for; whether a mail room, or a postal or telegraph office, or a refreshment room is required; if so, on which side of the station should any of these rooms be provided. **Number of passengers.** **Amount and nature of traffic.**

4. The kind and social rank of people who will use the station, so far as will help to determine the kind of waiting-room and other accommodation necessary. **Social rank of passengers.**

5. Whether fires or stoves will be required in the rooms or offices; if so, what kind are usual in the country, and what the kind of fuel. The method of lighting. **Fires, stoves, lighting.**

6. Information concerning the climate, building-materials, transport, water-supply, and drains. **Climate.** *See page 70, Part I.*

If provision has to be made for goods traffic, or a goods-station is required, the following additional information must be supplied. **Goods traffic.**

7. The number of goods or mineral trains expected to stop at the station, and the approximate number of wagons, distinguishing between inwards and outwards traffic, so as to show which predominates. **Number of trains.**

8. The nature of the merchandise sent from or to the station, and the weight of the heaviest pieces, so far as will determine the kind of buildings and cranes which will be required. **Kind and weight of goods.**

Shunting. 9. Whether much shunting will take place either of trains or trucks, and what siding accommodation will be necessary.

Roads and approaches. 10. The roads or approaches, and their levels, by which vehicles and goods will arrive at and leave the station.

Workshops. *Railway Workshops* are required principally for the repairs of locomotives and rolling-stock, and also for work connected with the permanent-way and signals. Economy both in the first cost and in the current expenditure in the workshops afterwards, depends to a large **Arrangement.** extent on the proper arrangement of the buildings and machinery at the commencement. It is sometimes convenient to adopt a standard **Roofs.** size and form of roof for all the sheds on the railway, roofing made in squares of 20 ft. or 40 ft. being supplied, so that any number may be *See* ROOFS. *Chap. XXVIII.* combined for any site. The roof principals may be made with advantage of the "saw" or "weaving-shed" shape, with a north light and **Columns.** ventilation. The stanchions or columns should all be suitable for attaching small lifting cranes, brackets for carrying shafting and some- *See* FACTORIES, *page 68.* times even for drilling-machines. The extent and the arrangement of workshops must be decided primarily by the length of railway and the amount of traffic to be provided for; and the greater the scale on which the workshops have to be built, the greater will be the **Subdivision of processes.** number of subdivisions that may be advantageously made for different processes. In colonies and places where private factories are not available for the ready purchase of materials and fittings, the **Workshops must be complete.** railway workshop must be complete in a way not necessary in manufacturing countries. Thus a small melting cupola with blower, and **Foundry needed.** a brass foundry should be established at the outset. On the other hand, in designing workshops for a small railway, the methods which obtain in larger shops, or on more important railways, should not be **Special tools not always required.** imitated, as special tools and systems which may be applicable in the one case, but which involve considerable outlay at the commencement, will be quite out of place in the smaller one. Not only have *See Chap. XXIII.*, MACHINE-TOOLS. new tools and automatic processes been invented for locomotive work, but lathes and other machines common to all engineering factories are adapted to special operations of detail, the need for which repeats itself so regularly as to keep machinery and men constantly employed. Thus, while in a small workshop the same wheel-lathes may serve for the very different work of turning large driving-wheels and small wagon wheels, in a large workshop separate lathes are set apart for each of these duties. Besides the ordinary

lathes, drilling-machines and other tools usual in all engineering and boiler factories (and described in another chapter), the following may be enumerated as special to a railway workshop :— *See Chap. XXIII.*

Special tools for locomotives.

Wheel-lathes; tire-boring machines; tire-blocking and stretching machines; lathes for the crank-axles of engines with inside cylinders; lathes for wagon and plain axles; crank-pin boring or quartering machines; multiple drills for tube plates; wheel-rim drilling machines; wheel-rim shaping machines; key-way drilling-machines; hydraulic presses for forcing wheels on and off their axles; cylinder-boring machines for a pair of cylinders; sheer-legs for lifting locomotives off their wheels; hydrants for washing out the engines.

Ordinary lathes may suffice. *See* LATHES, *page 308.*

Of the above, which are all fixed machines, some may be dispensed with in a small factory. Thus, there is no need to devote lathes specially to turning axles or boring cylinders, as an ordinary 12-in. screw-cutting lathe may serve for both these purposes; so also, tires may be bored out on the chuck of a wheel-lathe instead of on a special machine; crank-pin boring-machines may be dispensed with; one wheel-lathe may suffice, if made large enough for the largest kind of wheel, or even an ordinary gap lathe, useful for other purposes, may be sufficient. Besides the fixed machines, numerous *portable* machine-tools have been devised, which can be affixed to the work instead of detaching the pieces to be operated on from the locomotive and bringing them to the machine; the use of such machines allowing great economy in time and money. Thus, there are tapping-machines for the stays of fire-boxes, machines for cutting key-ways in eccentrics, and machines for re-boring cylinders while in their places. Other special appliances are being introduced into large locomotive workshops. Among these are hydraulic or other machines for testing springs; weighing machines for ascertaining the distribution of weight on the various axles; powerful travelling-cranes for lifting locomotives entire, and carrying them from one part of the shop to the other. Such cranes render unnecessary the sheers above referred to.

Portable machine-tools. **Special appliances.** *See* CRANES, *Chap. XXV.*

Capital outlay. **Cost of workshops.**

It is obvious that the extent to which the above tools can be adopted in any particular workshop, depends on the kind and amount of work to be done, and on the amount of capital available for it. Repairing-shops for a small railway employing only six locomotives and 100 vehicles would if built in England cost from £10,000 to £15,000, including machinery and tools, but £8,000 will generally suffice at the commencement. From this upwards there is hardly any limit; the outlay on some of the establishments for the principal

Sometimes excessive. *See page 305.*

English railways approaching a million sterling. Indeed, there is on some railways a tendency to create manufacturing establishments unduly large, which absorb much of the capital and management which should be devoted to the primary purpose of carrying traffic.

Running-sheds. **Stores.** **Tools and fittings.** *See page 259.* **Workmen's houses.** *See also page 63.*

Although one repairing-shop may suffice for a considerable length of railway, "running-sheds" are required wherever engines have to be sheltered; and it is usual to provide in such sheds water under pressure and stand-pipes for washing out the boilers, a furnace for drying sand, stores for such articles as gauge-glasses, piston-rings, and small parts often required, as well as for coal, oil, tallow, and waste. How far other tools may be added, such as a small lathe or smithy fire, depends on the distance from the repairing-shops and the likelihood of sudden local repairs being required. It is of course convenient to have a coal-stage and water-tank near to the running-shed. It is often also necessary or expedient, if there are no suitable houses near at hand, to provide dwellings for the foremen, engine-drivers, and others, so that they may be quickly summoned, and saved a long walk before and after working hours.

Information necessary.

The following information is that which is necessary as a basis for planning railway workshops and for selecting the most suitable tools:—

Extent of railway.

1. The length of the railway to be served by the workshops; whether a single or double line; the gauge of the railway and the number of train-miles run.

Number and kind of engines.

2. The number of locomotives on the railway, with a description of each type, including the weight and diameter of the largest wheel; and the approximate number in detail of each different kind of carriage or wagon.

Site. **Foundations.**

3. A plan and section of the land available for the workshops, showing the railway and the positions of the stations, buildings and sidings, and the road approaches. The likelihood of complaints of nuisance from the smoke caused by the engines. The nature of the soil and its suitability for foundations; the direction and system of the drainage.

Materials.

4. The building materials available, the climate and other local information as already described.

Nature and extent of work to be done.

5. The nature and extent of the work to be done; for instance, whether locomotives are to be made as well as repaired; whether carriages and trucks are to be made, and if so, whether everything will be done in the local workshops or the iron-work imported.

Making of wagons. *See Chap. XXII.*, ROLLING-STOCK.

6. When a railway is thoroughly established, it may be advantageous to make wagons, so as to save the cost of carriage from a manufactory, and to find employment for workmen whose primary duty may be in repairs. But it is seldom expedient to make other iron-work than the simplest forgings. Springs, buffers, and minor fittings are hardly ever made in railway workshops.

Timber.

7. The kind of timber used for the carriages and wagons, and the condition (logs, sawn-timber, or planks) in which it will arrive at the factory.

Iron and brass foundry.

8. Whether an iron or brass foundry is required, or whether the necessary castings can be purchased. Whether sand suitable for a foundry, or sand for the locomotive wheels, is obtainable.

Signals and permanent-way.

9. The kind of signals used on the railway should be described and anything special connected with the points or permanent-way which needs special repairs.

Fuel.

10. The kind of fuel used on the locomotives and obtainable for the factory engine and smiths' fires.

Water supply. *See page 258.*

11. The source of the water supply, and the quality and pressure of the water; the number of engines per day to be washed out or wanting water, and the capacity in gallons of the engine tanks.

Lighting.

12. The system of lighting the workshops which is to be adopted and whether gas-works are required.

Houses for Workmen.

13. Whether living accommodation is wanted for any of the workmen, foremen, or staff, and if so, for how many.

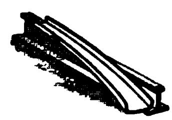
Plate-layers' tools.

Plate-layers' tools cost from £5 to £20 per set, and a proper selection depends on the following information:—

The extent of railway for which the tools are required; the amount of traffic as indicated by the number of trains per day or the number of train-miles; the gauge of the railway, and the width of the "six-foot;" the system of permanent-way, describing the section and weight of the rails, and the mode of fastening and jointing them; the weight of the engines; the climate; and the kind of workmen employed.

Ramps.

Ramps by which engines and wagons may be replaced on the line after accidental derailment are now generally used on railways. They cost from £2 to £3 each and weigh from 80 to 100 lbs., so that they may be carried on the engine or in the guard's carriage.



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[*See also* LOCOMOTIVES AND ROLLING STOCK: FACTORIES: *and in Part I.*, RAILWAYS.]

CHAPTER XXII.

RAILWAY EQUIPMENT (CONTINUED). LOCOMOTIVES AND ROLLING-STOCK.

Locomotives must be early considered in a railway project.

In the design and equipment of a new railway, the *Locomotives* should be considered at an early stage of the proceedings; for if this be not done, and the railway be laid out, and the gradients, curves, and permanent-way settled, the locomotive engineer, when his time comes, will find that he has to carry the traffic under conditions which he might have improved if he had been consulted earlier. The gauge of the railway, the kind of rails, and the strength of the bridges, should in a large measure depend on the size and power necessary in the engines; but these essential points are often irrevocably determined before the locomotives are thought of. It is evident that a powerful engine—if such be required—is crippled if a narrow gauge and light rail limit the size and accessibility of its working parts; while, on the other hand, a permanent-way may have been constructed unnecessarily wide or strong for the kind of locomotive which the gradients and traffic require.

Permanent-way must be suitable.

Choice of engine.

See pages 279 & 284.

Weight and speed of trains.

On every railway, the use of the most appropriate kind of train is an important factor in the economical working of the line; and, in conjunction with the gradients, it determines the power and class of engine that is required. Generally, heavy trains at slow speeds are preferable for mineral and through traffic, or where the movement is from one great centre to another, or where—as, for instance, in India or South America—fuel and wages are dear, while time is cheap. On the other hand, where the traffic is chiefly local, or consists of passengers or perishable goods, lighter trains, running at more frequent intervals, are required by the community, and are essential to profitable management.

Tractive force depends on adhesion.

The tractive power of a locomotive depends, not only on the force exerted by the steam on the pistons, but on the adhesion of the engine upon the rails, and therefore on the condition of the rails. The greatest adhesion is obtained when the rails are quite dry or very wet; the maximum under such circumstances being about one-fourth the insistant weight on the coupled wheels of the engine; that is to say, if the driving-wheels of the engine press with a weight of 20 tons on the rails, a tractive force of 5 tons can be exerted; but this maximum cannot be counted upon. One-seventh is a fair average; while one-tenth, or about 224 lbs. for each ton weight, may be considered the minimum. The last is an extreme case, which occurs only when the rails have become very slippery in damp, foggy, frosty, or snowy weather. In such cases, if the train-load exceeds what this reduced adhesion will draw, the driving-wheels, instead of advancing, will slip round, although the slipperiness may be to some extent counteracted by the sprinkling of dry sand on the rails. In hot, dry countries the wheels seldom slip; in England the slipperiness varies with the weather, and is often very great; while in certain seasons or after dew-fall in moist countries, like the Mauritius and the west coast of South America, slipping can hardly be avoided by sprinkling sand in front of each coupled wheel.

Insistant weight on the driving-wheels.

Slippery rails.

Influences of climate.

Haulage force.

On a level well-laid road, engines can draw very heavy loads, as the only resistance then to be overcome is the friction of the axles in their bearings, the wheels on the rails, and of the air or wind. On the best English lines, where the permanent-way and the rolling-stock are in good condition, the total from these causes is so slight that the resistance to haulage of a passenger train, when running on a level track at 15 miles an hour, is only from 3 to 6 lbs. per ton weight of train (though about treble this force is necessary to start a train); but the resistance, owing to oscillation and greater air pressure, increases with the speed, so that at 40 miles an hour the resistance would be from 14 to 18 lbs. per ton. The higher speed therefore involves a greater expenditure of steam, and consequent consumption of fuel. The maximum speed which can be attained depends greatly on the condition of the road and rolling-stock, so that, while on the best English lines, passenger trains sometimes run 70 miles an hour, a speed of 40 or 50 miles would be the maximum attainable with the same tractive force on less perfect lines. If the rails be badly laid or much worn, or the rolling-stock be in bad condition, the friction is increased, and instead of 3 or 6 lbs. per ton, the resistance and

Train resistance.

Increases with speed of trains.

Maximum speed.

haulage even of a passenger-train would be 10 lbs. or more; and in countries where the railways have been too cheaply or hastily constructed, or are badly maintained, the expenses of haulage are very high. The resistance to haulage of a goods train, when moving at a speed of from 15 to 20 miles an hour, ranges from 10 to 16 lbs. per ton weight of train.

Goods trains.

Gradients.

It is however the maximum or ruling gradient of a railway which mainly determines the power necessary in the engine, and if railways could only be made level, engines might be much smaller and lighter than they are, or the trains much heavier. In ascending an incline, the gravity of the train has to be overcome; and in this respect, a train on a railway has no advantage over a vehicle on an ordinary road. As has already been described, the dead weight of the train has to be lifted, so that a gradient of even 1 in 100 adds one-hundredth part of a ton, or 22½ lbs. to the haulage force required for each ton weight of a train. Thus, if 10 lbs. be sufficient for the haulage of each ton on a level, the resistance is more than trebled. A gradient of 1 in 50 would add 45 lbs. to the 10 lbs., and so on. As an example, a locomotive having an insistant weight on the coupled wheels of 20 tons will have (reckoning one-seventh of the weight) a tractive force of 6,400 lbs., and at the rate of 10 lbs. haulage resistance per ton of load, will draw a train of 640 tons on a level track. But on an incline of 1 in 200 the resistance is 21¼ lbs. instead of 10 lbs., and the engine will draw only 300 tons; on a gradient of 1 in 100, 200 tons; on one 1 in 50, 116 tons; and on 1 in 20 only 52 tons. It is for the above reasons that considerable expense in cuttings, tunnels, and embankments is incurred in order to make a railway as level as possible. The greater the traffic expected, the more justification is there for such expenditure, as the saving in haulage outweighs the interest on the extra capital expended. But the necessity or desire for cheap first cost, which often leads to the construction of railways with steep gradients, involves expense in other ways. The engines, in order to have adhesive force to overcome the greater resistance, must be made heavier than for level roads; the rails must therefore be stronger and more expensive; and the expenses of fuel and maintenance are increased. These circumstances and the disadvantages above described are not always sufficiently appreciated when it is attempted to economise in construction. Gradients steeper than 1 in 100 seldom occur on English main lines, but where the advantages of

Gravity resistance. *See page 240, Part I.*

Incline of 1 in 100 trebles resistance.

Examples.

Steep gradients to be avoided. *See page 59, Part I.*

Extra capital cost repaid by cheaper haulage.

Maximum gradients. **Special engines.**

railway communication are not otherwise attainable, much steeper gradients may be surmounted. An incline of 1 in 20 is seldom met with and is still more rarely exceeded by trains drawn or pushed by ordinary locomotives; but by special contrivances steeper inclines may be overcome. The objections to very steep gradients lie in the descent as well as in the ascent, and although locomotives have been made to haul (with no other grip on the rails than their adhesion-weight affords) loads up gradients as steep as 1 in 15, no system of brake-power by which merely the gravity weight of the engine skidding on the rails is made effective, would render the descent of such

Risks in descent.

a gradient safe with a load as great as the engine could haul up. And unless the road be in good condition, a gradient of 1 in 20 would in the same way be dangerous. On the railway over Mont

Centre rail.

Cenis, in operation before the tunnel was completed, the "Fell" system of a centre rail was successful on gradients as steep as 1 in 12. The centre rail, with wheels pressing sideways upon it, was as necessary for safety in descent as for power in ascent. On the

Toothed wheels.

Rhigi mountain railway, toothed wheels upon the engine, gearing into a rack laid between the rails, enable the engine to climb a gradient of 1 in 3, and to descend in safety. A more simple plan,

Trains drawn by fixed engine.

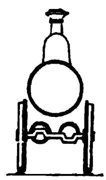
which involves no alteration of the rails, has been successfully tried on railways generally level but with occasional steep gradients. By this plan, the locomotive is detached from the train at the foot of the incline, so that thus unburdened, its adhesion-weight is sufficient for its own ascent; and on arriving at the summit, it is anchored to the rails and, as a fixed engine with a revolving drum, winds up the

Winding-engine.

carriages by a rope or chain. But much time is lost by such an operation, and a special locomotive for the steep gradient, or a fixed winding-engine, would generally be found more effective.

Classification of locomotives.

Locomotives differ so variously that they can only be classified broadly according to some of their leading features. The position of the cylinders, inside or outside the framing, is one important point of difference, and engines may be divided into two classes accordingly. Inside cylinders are generally preferred in England, and outside cylinders almost universally on the Continent and in the United States. Inside cylinders require the use of cranked axles, and crowd the working parts of the engine so as to render them less accessible



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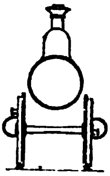
Inside cylinders.

than when the cylinders are farther apart. On the other hand, engines with inside cylinders are lighter and allow of certain economies in manufacture; but the chief reason for their use in England has been



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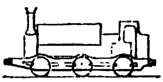
Outside cylinders.

the supposed greater steadiness when the engine is running, than if the cylinders projected over the rails, and the less wear on the journals of the axles. In countries where slow speeds are usual, any unsteadiness which might be caused by outside cylinders is of less consequence. Besides this, the boiler, and therefore the centre of gravity, can be placed lower with outside than with inside cylinders, and many English engineers who have had great experience with various kinds of engines and railways, do not agree in attributing disadvantages to outside cylinders; and the whole question is one on which there is much difference of opinion.

Arrangement of tenders.

Another classification of engines is that according to the mode of carrying fuel and water, the arrangements for this being determined mainly by the distance to be run without stopping. The long tenders necessary for runs of from 70 to 100 miles are unnecessary in trains stopping more frequently, and tenders are made to suit the service required. A *Tank-engine* has no separate tender, but carries its water either in a tank on the boiler or on each side of it, and the fuel in bunkers behind or on each side of the foot-plate; the position of the water and fuel being determined by what is necessary to a proper distribution of the load upon the different wheels. If carefully designed in these respects, and well made, a tank-engine will run steadily and, on a steep incline, will haul a greater paying load than a tender engine of similar power, but with less adhesion weight on the rails (all the wheels of the engine being in either case rendered effective by coupling), because in the latter case, as the tender has to be hauled, its weight is included in that of the train, while in a tank-engine the load of fuel and water is effective as adhesion-weight and the haulage force is all available for the train. On narrow-gauge railways with light rails these circumstances are in favour of a tank-engine for steep inclines.



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Tank-engines.

Advantages on steep inclines.

As compared with tender-engines.

Limits of distance.

Tank-engines are preferable for short runs, branch lines, shunting at stations, and for contractors' purposes; but they cannot carry sufficient fuel for long runs, and the side tanks, unless carefully balanced, render them unsteady at quick speeds or on uneven roads.

Limits of weight.

Moreover, there is for any but very strongly-made railways a limit of size to these engines, because if made with boilers and cylinders of large capacity, the additional weight of water-tanks and fuel on a short wheel-base imposes too great a load on the rails and bridges.

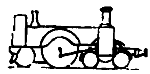
Maximum weight of tank-engines.

See page 129, Part I.

But very powerful tank-engines are occasionally used, the heaviest having a load of 16 tons on each of three pairs of wheels, or a total of 48

tons on a wheel-base of 16 ft. Engines of this kind strain small bridges more than the heaviest tender-engines, and the strength of the permanent-way and bridges should be considered before such an engine is chosen.

Another classification of engines may be made according to the coupling of the wheels. By coupling one or more pairs of wheels to the pair on the crank or driving axle, the adhesion-weight on all the wheels so connected is rendered effective. Thus, there are "single" engines in which the driving-wheels are not coupled on to the other axles, and only the weight on the one pair of driving-wheels is effective for adhesion; "four-wheel-coupled" engines, in which two axles or pairs of wheels are connected together; "six-coupled" engines with three pairs of wheels coupled; and finally, "eight-coupled" engines with four pairs of wheels coupled. For passenger trains on easy gradients, where a high speed is required, an engine with one pair of driving-wheels is sometimes used, because, while the weight on one pair of wheels affords sufficient adhesion for a light load, the arrangement is favourable to quick running. Single engines will draw considerable loads on well-laid lines, and even gradients as steep as 1 in 100 do not hinder their use. When once a speed of 30 miles an hour is attained, these engines compare favourably with coupled engines; but while they may be thus sufficient for long runs without stopping, it is difficult with them to start any but a light train, especially if on an incline or on slippery rails; and they are therefore unsuitable where such circumstances are likely to occur. Moreover, with increasing traffic and heavier rolling-stock, the weight of trains has tended to increase, and the concentration on one pair of wheels of the load necessary for adhesion is trying to the permanent-way and bridges on any but strongly-made lines. Their use, which was confined to Great Britain and France, has been to a large extent abandoned in these countries also; but though it is found that four-coupled engines are sufficient for speeds up to 50 miles an hour, and, under favourable conditions, even for 60 miles an hour, single engines are undoubtedly best for light trains running at high speed on a level railway, and continue (1880) to be used on some of the best English lines. The risk of coupling-rods breaking, which is often a cause of accident, is of course avoided by the use of single engines which have no coupling-rods. Four-wheel-coupled engines are usual for passenger trains, and light quickly-running goods trains on easy gradients, but for general goods traffic



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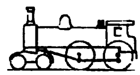
Single engines.



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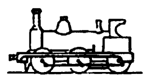
Four-wheel-coupled engines.



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Six-wheel-coupled engine.

Disadvantages of single engines.

Not suited for heavy loads.

But best for quick light trains.

Uses of coupled engines.

three pairs of wheels are coupled. It is not that engines with two pairs coupled are insufficient when once in motion, but they are often unequal to the starting of heavy trains, and therefore are not suitable where much shunting is required. They find their best use in drawing high-speed light goods trains. The coupling of more than three pairs of wheels is seldom exceeded in England, but on the Continent and in the United States, where heavy goods trains are taken over permanent-ways not strong enough for great adhesion-weights concentrated on a few wheels, four, and even in some cases more, pairs of wheels are coupled together. In the distribution of weight on the wheels, and in arranging the total weight of engine and tender on a wheel-base of certain length, the sufficiency of the permanent-way and bridges to sustain such loads without injury is an important point to be considered.

Eight-wheel coupled engines.

See BRIDGES, *Part I.*

Fuel consumption.

On most railways, fuel, tubes, and tires form the three main items on which the expenses of wear and tear in running are incurred. Various points in the design of a locomotive depend on the kind of fuel to be used. Almost every kind of coal can be burnt, but the fire-box, grate, tubes, blast-pipe, and other parts have to be specially arranged to suit the kind of fuel to be used. The generation of steam, and the maintenance of sufficient pressure, depend on the skill of the driver and firemen, who should attain these objects with the least possible expenditure of fuel, an important item in the economy of railway working. On English railways, the consumption of coal ranges from $2\frac{1}{2}$ lbs. to 4 lbs. per indicated horse-power per hour. For passenger trains the consumption per mile ranges from 15 lbs. for light trains at moderate speeds to 30 lbs. for heavy trains, and even this is exceeded for trains which have to stop very frequently. For goods trains the consumption varies from 35 lbs. for light express goods trains to 50 lbs. for heavy mineral trains. It is generally attempted by supervision and a system of rewards to give to the men engaged a share in the saving below a fixed standard of consumption. Wood fuel requires a sharp blast to promote consumption, and produces abundant sparks, which, to prevent the ignition of herbage or trees, or even the train itself, must be consumed or stopped in the chimney by a suitable contrivance. In Europe, railways are almost always fenced in from the surrounding land; but in countries where this expense is avoided, cattle-guards of a peculiar kind must be provided for clearing the track of straying cattle or wild animals.

Depends on skill of engine-driver.

Consumption per indicated H.P.

See page 162.

Consumption per train-mile.

Wood fuel.

Cattle-guards.

Most of the improvements which have been made in locomotives since 1860 are applicable to all the types just described. Greater power than formerly is obtained; and, by a compact arrangement of parts, cylinders of 17½ in. and even 18 in. diameter are placed without inconvenience within the framing of standard-gauge (4 ft. 8½ in.) engines, the increased piston-area so obtained being very considerable. Improved boilers and fire-boxes facilitate rapid combustion and the generation of sufficient steam for such large cylinders. As boiler space is limited on a locomotive, it has been sought to increase the power by higher pressures of steam, but there are certain difficulties which limit any great alteration in this respect. From 130 lbs. to 140 lbs. per square inch are usual working pressures in England, and on a few railways 160 lbs. is customary; and on some foreign lines 180 lbs. prevails, while the pressure customary in other kinds of steam-engines seldom attains 100 lbs. The maximum average pressure on the piston for a sustained effort, such as in surmounting a long incline, is from three-fifths to three-fourths of the boiler pressure; for a short distance, or at starting, this may be exceeded; while, at full speed, only about one-third of the boiler pressure can be reckoned on. The highest piston-speed ranges from about 500 ft. per minute for a goods-train engine at 20 miles an hour, to about 1,000 ft. per minute for an express passenger-engine running at 60 miles an hour.

Modern improvements in locomotives.

Larger cylinders.

Boilers.

Steam pressure.

See pages 169 & 183.

See page 169.

Pressure on piston.

Piston-speed.

Some of the most important improvements have been directed towards the giving of more lateral play to the wheels. By what may be termed the ordinary mode of construction, the various axles of the engine are so placed in one rigid frame as to be always parallel to each other, while for easy passage round sharp curves, radiating axles are desirable. On sharp curves the rigid wheel-base imposes severe strains both on the engine and on the permanent-way; and when high speeds have been attempted, this has often been the cause of accident. These evils were felt most on railways having sharp curves and imperfect permanent-way, but on well-laid lines the evil of sharp curves is largely counteracted by raising the outer rail, so that the force of gravity tends to draw the train into the curve, and thus to neutralize the straightforward motion which its direct impetus causes. English engineers, having a high standard of excellence in these respects, were slow to recognise the necessity for alteration; and although bogie-engines were at an early date made in England, locomotives of the ordinary kind continued

Rigid wheel-base.

Passing round curves.

Raising of outer rail.

Bogie-engines.

See Figs. 140, 141.

to be exported for use even on railways where the road and curves were unsuited to their use. Bogie-engines for meeting the difficulty were first made on a considerable scale in the United States, and have since been widely adopted in Europe and elsewhere. There are several forms of bogies, but the general principle in all, is that of a detached truck or carriage on two or four wheels, carrying one of the ends of the engine, which is so pivoted or connected to the bogie-carriage that the latter has an independent lateral and radial motion in passing round sharp curves; thus avoiding the sudden wrenching and side strains to which an engine on a rigid wheel-base is liable. The use of bogies also tends to greater steadiness in running on badly-laid roads. Although engines thus articulated run more freely and safely than with a rigid wheel-base, there is still room for improvement for railways having sharp curves. As, in passing round a curve, the distance to be travelled on the inner rail is less than that on the outer rail, and as, even with bogies, the wheels are firmly fixed to the axles, the inner wheel has to drag or skid. It has been attempted to remedy this by making one or both wheels revolve loosely on the axle, but this plan has for various reasons proved impracticable. There is the disadvantage in the use of the bogie that the weight carried on it cannot be rendered effective for adhesion, and in cases where the maximum haulage power is wanted and where the curves are of moderate radius, bogies should be avoided. Steam brakes have been extensively adopted for goods engines, and are found of great use in giving to a driver more control over his train; they also allow considerable saving in time in shunting. Continuous brakes, most of which are worked from the engine by the driver, will no doubt be ultimately used on all important passenger trains.

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Bogie trucks.

Other improvements needed.

Steam brakes. *See page 283.*

Continuous brakes. *See page 295.*

While, as just described, the most conspicuous alterations have been in the direction of greater power and flexibility, various improvements in detail have at the same time taken place. Steel is used for boilers, tires, axles, slide-bars, piston-rods, coupling-rods, and other important parts, but it has not as yet (1880) been found so effective as brass for tubes or so trustworthy as copper for fire-boxes; increased area and improved lubrication have been given to bearing surfaces; improvements in boilers, such as increased water-space, stronger seams and stays, steam or hydraulic riveting, have together tended to increased durability and to a lessened cost of repairs. A more systematic method of manufacture, subdivision of labour,

Modern use of steel in locomotives.

Improved boilers.

and the use of special machine-tools have together reduced cost, and at the same time improved the quality of the workmanship. In English-made locomotives a handsome appearance is sought rather by the just proportioning of parts, symmetrical outlines, and graceful curves, none of which involve extra cost, than by unnecessary paint and ornamental brass-work, which are frequently a cover for bad design, workmanship, or material. The simpler designs are compatible with that good appearance of the engine, which induces pride and care in the engine-driver.

Systematized manufacture.

Simplicity in design.

Locomotives are complex and hard-worked machines, and defects, whether in materials or workmanship, soon betray themselves in some slight or serious accident, causing delays on the road or general inefficiency. The time and money expended in repairs and renewals from these defects are, especially in countries distant from the place of manufacture, very great, and it is obviously important to ensure, by correct and simple design, by the employment of capable manufacturers, and by proper supervision, that the most suitable engines shall be obtained. If these precautions are neglected, or a supposed cheapness allowed to prevail, cause and effect will probably be exhibited in some of the following ways:—If brass of inferior quality has been used, the bearings become heated and the valves wear out: tires too soft become loose, wear hollow, cut their flanges, and require re-turning; tires too hard are liable to fracture at high speeds: the link-motion, if not well hardened and properly hung, soon wears loose, rattles, and gives an extravagant and unequal distribution of steam to the cylinders; while the cylinders, if of soft or inferior metal, will soon become so worn as to require re-boring and re-facing. Such are a few examples of defects in the wearing parts, and results even more serious occur if the boiler be badly made. Bad caulking, or rivet-holes which are not properly filled by the rivets, soon reveal themselves; imperfect tubes become leaky and furrowed; a burnt fire-box, or a tube bursting during work, causes an annoying stoppage.

Defects in locomotives.

Involve trouble and expense.

Examples of defective wearing-parts.

Defective boilers.

In England, the quicker speeds and the greater traffic than those of foreign railways have led to a high standard of excellence in these respects, which has been followed in the engines made in England for Indian, colonial, and foreign railways. In Europe, English-made engines stand pre-eminent, but in America, owing to many different circumstances, other types of engines and methods of construction have prevailed; and engines made in the United States have been preferred on some railways formerly supplied from

High standard of excellence in English engines.

American engines.

England, partly because of their greater suitability to the roads and partly from supposed cheapness.

Cheapness, how obtained.

A less cost is allowed by the use of thinner boilers (which restricts the pressure of steam), thinner wheel-tires, steel fire-boxes instead of copper, iron tubes instead of brass, lighter framing, cast-iron wheels, and the cheapening of various minor details. Both in England and America the driving-wheels have steel tires; but in England all the wheels of the engine have their centres or skeletons of forged iron, while in America cast-iron at one-fourth the cost is invariably used, and as there are about three tons of such wheels in one engine, the saving is very great. The wheels of the engine other than the driving-wheels are, in America, made of solid chilled cast-iron, without separate tires; and these wheels are harder than steel, but their life ends when the chilled part is worn away; they are not so trustworthy, and, not having been turned in a lathe, are not so truly formed. Unless the amount of fuel consumed and the cost and inconvenience of repairs and renewals over a long term of years be taken into account, a low first cost is no criterion of cheapness; and although it is sometimes difficult to separate expenses arising from an ill-kept road or peculiar methods of working from those caused by defects in the locomotive, it is necessary to analyse these circumstances and allot them to their proper causes before a fair comparison can be made.

Lighter parts.

Chilled cast-iron wheels. *See also page 292.*

Cost of fuel and repairs must be reckoned.

American methods of manufacture.

Differences in the methods of manufacture in England and the United States are caused also by other circumstances besides those referred to above. In England, not only do the types of engines differ to an extent beyond that prevailing on most railways abroad, but each succeeding engineer gives play to new individual predilections, and the types of engines are again multiplied. This mode of proceeding has its advantages and drawbacks. Assuming capacity in the engineer, no one can better appreciate the exigencies of traffic or the peculiarities of the railway than he who has to meet them, and on whom fall all the trouble of repairs and the responsibility for accident; and as no two railways are exactly alike in all the conditions of permanent-way, curves, gradients, rolling-stock, and traffic, it is an advantage on each railway to have locomotives specially adapted to their purpose. But there is the disadvantage that no standard types of engines can be arrived at while different kinds are demanded for every separate railway, nor can the cheapness in manufacture which exact repetition allows be obtained. In the earlier days of railways, however, there

Variety of type in England a cause of expense.

were few engineers who could design locomotives, and few manufacturers with experience to make them; and on the home and foreign railways supplied from England, the types of the leading makers were accepted without question. And while in Europe this system has been superseded by that described above of locomotive superintendents choosing or designing the exact kind they want, the necessary knowledge is not in the United States so widely spread, and the designing of the engines is generally left (as is the case also with bridges and other equipment) to the manufacturers, though on a few of the leading railways the engineers are beginning to design their own locomotives. But the majority of the engines are of types established by manufacturers, who having thus a repetition assured to them, can make cheaply in the same way that portable engines are made in England. And in countries where money is scarce, or the rate of interest high, cheap construction and low-priced engines may be an essential condition of railway enterprise; and the fact that a well-made road and an English engine will by their greater durability eventually prove cheapest, may be no inducement to their adoption. Each system has its advantages, but there is no common basis on which to make a comparison in price between English and American engines, and in either country, if the design of the other be presented, the price would be necessarily dearer than for engines of an accustomed kind.

Makers' types not now accepted in England.

As in America.

See page 121, Part I.

Cheap first cost important

Accustomed designs cheapest.

A new design involves more expense than is generally known. A complete set of entirely new drawings for a locomotive will cost from £100 to £200, while the patterns and templates will add from £100 to £150 more, but existing drawings can generally be adapted for from £50 to £100. Purchasers of locomotives sometimes stipulate that a set of drawings and templates be supplied to them, so that they are not afterwards bound to purchase new engines of the same design from the same maker.

Expense of new designs.

Cost of new drawings and patterns.

The kind of engine best suited for any particular railway depends primarily on the road, the gradients, and the nature of the traffic; but these important considerations are mixed up with others which vary almost in every case. On a large or busy railway, where numerous locomotives are required, different kinds may be selected for each branch of service. Thus, there may be "single" engines (one pair of driving-wheels) for light quickly-running passenger trains, four-wheeled-coupled engines for heavy passenger trains and fast

Choice of engine.

See pages 268 & 284.

Variety of kind, where useful.

See page 273.

goods trains, six-wheel-coupled engines for heavy goods trains, and tank-engines for local traffic and station or shunting work; while if on one section of the line there are steep gradients, specially-constructed engines may be provided for this district alone. But, on small railways, where but few engines are required, it is advisable to have them of an uniform type, capable of taking any of the trains over every part of the line. If this principle be adopted, the most difficult service on the railway will have to determine what type of engine shall be selected.

Uniform type best for small railways.

But even where various types of engines may be required on the same railway, it may still be possible and advantageous so to arrange the designs of the engines as to have their important parts alike and interchangeable. Thus, the boilers, cylinders, valve-motions, springs, and axle-boxes may be identical, and the differences in power which are required may be obtained by varying the diameter of the wheels and the method of coupling them, and by alterations in the framing thus rendered necessary. But it is very difficult to ensure such uniformity of parts if engines are bought from different manufacturers.

Parts interchangeable though engines differ.

Conditions of purchase.

To secure a good engine at a reasonable price, the specification, while stringent on all essential points, should avoid arbitrary conditions on minor points, which cause extra trouble and expense to the manufacturer without any corresponding advantage to the purchaser. But whether furnished by the buyer or seller, the specification should describe the important parts of the engine, for without such a description it is impossible to measure or compare prices. The gauge, the type of engine, inside or outside cylinders, and the number of coupled wheels having been recited, the following points are usually enumerated:—The size of boiler, thickness and quality of plates, and mode of riveting; the heating surface in the fire-box, the material (copper, iron, or steel) of which it is made, and a description of the staying; the number, size, and kind of tubes; the diameter of the wheels and axles, and the material of which they and the wheel-tires are made; the kind of axle-boxes and their fittings; the size of the cylinders and the kind of pistons; the capacity of the water-tank and fuel space; the brake arrangements. It is customary to include in the price of the engine the various minor parts necessary to its working; but as different makers do not supply the same kind and number of accessories, they should be enumerated when the price is arranged. It is

Specification.

See pages 11 & 178.

Materials and principal dimensions.

Accessory parts enumerated.

See also page 180.

also usual to specify the mode of testing, of painting and packing, and to state the weight.

When engines are bought for exportation to a country where skilled workmen are rare, and repairs expensive, special precautions to render the engines durable and easy of repair can be taken, that would not be expedient or economical for a railway where repairs are easy, and where spare engines are always available to take the place of those temporarily withdrawn from service. Thus, the water-space of the boiler may be made larger; and the bearing surfaces ample, with means of taking up the wear, even if these provisions entail the disadvantage of extra weight and increased first cost. The effective case-hardening of moving joints (a process often omitted or imperfectly performed) should be ensured; parts especially liable to wear and fracture should be provided in duplicate to an extent far beyond what would be proper in the country of manufacture; and the extra outlay so incurred considered as a prudent security against greater expense afterwards. Fire-bars, tubes, gauge-glasses, piston-rings, brasses for the connecting-rods and coupling-rods and for the axle-boxes, are among the most important of the spare parts required. The list of such extra parts needs very careful consideration, and the value of the articles enumerated should be duly weighed in comparing the offers of different manufacturers.

Purchase for exportation.

See Chap. XV.

Parts made durable and easy to repair.

See page 179.

Duplicate and spare parts.

See pages 41 & 150.

The current prices of locomotives fluctuate considerably, not only with the cost of labour and materials, but according to the demand. There are (1880) in Great Britain about a dozen manufacturers of locomotives who confine themselves almost entirely to this one branch of engineering, and in addition to these, the principal railway companies make new locomotives, although few make all that they require. Many of the railway workshops, established principally for repairs, have outgrown their purpose, and the gigantic factories which have been erected for making engines and rolling-stock are of doubtful profit to the shareholders who own them. Having, however, been established, they are employed, much to the disadvantage of the private manufacturers, who could, probably, if prices and costs were analysed, with profit to themselves, supply engines cheaper. But while it is seldom that engines are made so cheaply in railway workshops as in private factories, the great advantage may be more readily obtained of having exact similarity and interchangeability of parts. During the ten years ending 1880, if extreme high or low fluctuations be excepted, the following have been average prices :—A passenger

Prices of engines fluctuate.

English makers.

Railway workshops.

See page 264.

Not so cheap as private factories.

But allow similarity.

Prices. **Weights.**

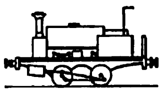
engine and tender of the best modern kind, with cylinders 17½ in. diameter, 24 in. stroke, equipped as usual on the principal English railways, has ranged in price from £2,200 to £2,500, and as the total weight of such an engine and tender (when empty) would be from 45 to 55 tons, it will be seen that the prices are equivalent to from £50 to £60 per ton. But although it may be convenient sometimes to compare values in this way, any such estimate needs qualification, and can only be approximate, for the cost of a tender per ton is only about half that of an engine, and the proportion which the weight of the tender bears to that of the engine varies according to the kind of both. The above prices would embrace the average price of the best and most powerful kind made for European, Indian, and colonial railways. Powerful tank-engines, as used in England, sell for from £1,800 to £2,200, or, at a weight of 35 tons, equivalent to £50 to £60 per ton. The extra cost of fitting a continuous brake to an engine ranges from £80 to £120 for a tank-engine to from £120 to £150 for an engine and tender. A steam-brake can be similarly applied for from £50 to £70 less than these prices. In either case, the ordinary hand-brake can be worked independently of the continuous brake.

Prices of large tank-engines.

Extra cost of brakes.

Contractors' engines.

The locomotives used by contractors in the construction of public works are almost invariably made as tank-engines, and as there are manufacturers who make a specialty of this class of engine, it is expedient to take advantage of the skill and experience by which the proportioning of the parts, the division of the weights on the wheels, and the balancing of the tank have been adapted to the purpose in view. A contractors' engine (for a 4 ft. 8½ in.-gauge railway) with outside cylinders 10 in. diameter and with 4 wheels coupled would cost about £900, would weigh about 11 tons empty and about 14 tons when equipped with coal and water. All the weight is effective for adhesion, but as the temporary roads used by contractors are uneven, and the wagons not usually in such good condition or so easy of haulage as ordinary rolling-stock, such engines when so employed cannot be safely reckoned on for hauling more than 85 tons on a gradient of 1 in 100, or 45 on a gradient of 1 in 50. An engine with inside cylinders 12 in. diameter and with 6 wheels coupled would cost about £1,200 and weigh about 14 tons when empty and about 17 tons when loaded. Such an engine would draw a load of about 140 tons of contractors' wagons on a gradient of 1 in 100 or 85 tons on a gradient of 1 in 50. But when used



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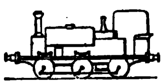

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Engines with tenders.

Little engines.

See page 243. And page 63, Part I.

Cost of packing.

See pages 41 & 180.

Time required for manufacture.

under better conditions these engines will haul heavier loads. The tender-engines made in England for narrow-gauge railways (mètre, or 3 ft. 6 in. gauge) with cylinders of from 10 to 14 in. diameter, and weighing from 15 to 30 tons, have sold for £1,100 to £1,600 per engine and tender. Similar engines with side or saddle tanks, and weighing from 11 to 20 tons, cost from £900 to £1,400. Small locomotives, for railways of less than a mètre gauge, cost from £400 for the little 2 ft. gauge, 5-in.-cylinder engine weighing 2¼ tons; £600 for a 3 ft. gauge, 7-in. cylinder engine weighing 7 tons, to £1,300 for the 3 ft. or mètre gauge engine weighing 15 tons. All the foregoing prices are exclusive of packing for export and of the cost of duplicate parts. Packing adds about 2 per cent. to the price, and duplicate parts add from 5 to 15 per cent., according to the quantity supplied, which, as has been said, should be determined mainly by the remoteness of the country and the difficulty there of renewing worn parts. A manufacturer requires from five to six months to make a locomotive from a new design, but those made of an established type can be made in from two to four months, according to size.

Engines tested.

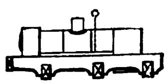
Stripped for shipment.

Weight of pieces and cases.

Separation of parts.

See page 40.

An engine, having been completed at the manufactory and made ready for the road, is tested under steam. The wheels having been raised from the ground, the engine is set to work, so that the tightness of the boiler, the efficient working of the injector and pipes, the smooth working of the motion, and the action of similar important parts can be tried and defects observed. After having been examined and approved, the engine, if for export, is taken to pieces and all the fittings removed. The smaller parts of the engine are packed in cases, of which from 10 to 20 are required, according to the size of the engine and the weight in each case. The cases weigh from 10 to 20 cwt. each, but it is generally considered inexpedient to have more than 10 cwt. in any one case. Each axle with its pair of wheels upon it is shipped as one piece. The engine is thus stripped until nothing but boiler, cylinders, and frame remain together. This one piece or "body" generally forms about half the total weight of the engine when empty. If, however, this weight is difficult to deal with, either in transport or at the place of arrival, it can be reduced by removing the boiler from the frame; but this involves, of course, more labour in putting the engine together again than would otherwise be required. The finished surfaces, and other vulnerable parts are protected, and baulks of wood on which the weight can rest are attached to the frame, generally by fixing them in the places of the



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axle-boxes. The "body" is lifted by chains passed under the boiler at the places (previously ascertained by experiment and marked) where the weight will be evenly suspended. The same careful adjustment of the lifting-chains is again necessary when the weight is lowered into the hold of a vessel and when landed at the port of arrival.

See CRANES.

Delivery alongside. Makers generally contract to deliver alongside the export vessel, and do not undertake the duty of placing on board. It is usual to paint the engine plainly, leaving decorative painting and varnishing to be done after the engine is re-erected.

Large hatchways. On large modern steamers, the hatchways are generally large enough to receive locomotives; but in some cases very great trouble is caused, especially at the unloading from the vessel, as in many foreign ports there are not the facilities which the powerful cranes in English ports afford. The space around the engine is generally packed with other goods, sometimes even with coal, if the parts liable to damage are protected against surface damage. On short voyages, in favourable seasons, locomotives are sometimes carried on deck; but in such cases a higher rate of insurance has to be paid.

See page 37.

Stowage on shipboard.

Rates of freight. The cost of freight has always to be specially arranged, as the rates for ordinary machinery are never sufficient for the extra trouble and risk which are involved.

See page 35.

Choice or design of engine, how determined. To enable an engineer to design or select a locomotive suited to the purpose in view, he should be informed on the following points, an acquaintance with all of which are necessary to a proper choice:—

Gauge and strength of permanent-way. 1. The gauge of the railway; the section and weight of the rails; the kind of permanent-way, the distance apart of the sleepers, and the condition, good or otherwise, in which it is kept. In addition to, or instead of, information concerning the condition of the permanent-way, a direction as to the maximum weight permitted on any one pair of wheels may be given.

Strength and headway of bridges. 2. The strength of the under bridges, not only in regard to the total load they will sustain within proper limits of safety, but also the fitness of the cross girders or other rail supports for sustaining a concentrated load on any point; the height and width of over-bridges and tunnels so far as these dimensions affect the height and width or "loading-gauge" of the engines passing under; the particulars and the height of couplings from the rail level, and the height and width of buffers, in the existing engines and rolling-stock, to which conformity is necessary; the length of the turn-tables on the railway, and the standing space available in the running-sheds.

See page 143, Part I.

Loading-gauge.

See page 287.

Couplings, turn-tables, sheds.

3. The length of the railway, the radius of the sharpest curve, and the inclination, length, and position of the steepest gradients. The position of the gradients is important for various reasons. An ascent may be rendered less formidable by a descent immediately preceding it; an ascent at or close to a station renders starting difficult. A complete section of the railway showing the stations best supplies this information. The altitude of the railway above the sea (if it is high) should also be stated. **Radius of curves.** **Gradients.**

4. The nature of the traffic, and the maximum gross load exclusive of the engine, to be taken up the steepest incline. The average speed of the trains. **Weight and speed of trains.**

5. If continuous brakes are in use or are required on the engine, their kind. If the engine is for hauling goods trains, whether a steam-brake is required. **Brakes.**

6. The kind of fuel and water available; the distance apart of the stations at which supplies can be obtained; and the distance which the engines will have to run without stopping. **Fuel; water.**

7. The nature of the climate, so far as it may cause rails to be slippery, or the occurrence of heavy snow-falls, or inclement weather rendering special protection for the driver necessary. Frost renders necessary special kinds of oil-cups or arrangements for oiling; heavy snow-falls require snow-shields on the engine, and snow-ploughs; much dust renders necessary special coverings for bearings. **Climate.** **Frost, snow, dust.**

8. The nature of the crops, herbage, or trees by the railway, and the condition of the fences, so far as these circumstances may determine the need for spark-arresters and cattle-guards. **Spark-arresters.**

9. The facilities for repairs both in regard to workmen and workshops. The kind of engines already in use, the name of the maker, and the reasons, if any, for or against imitating them all or in part. Special defects or contingencies arising from local circumstances should be noted. **Facilities for repairs.**

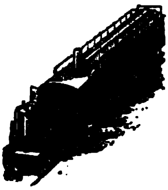
10. Such particulars as to destination and the means of transport as may determine the method of subdivision and packing. *See pages 35–40.*

The small engines for working tramcars, though of a peculiar kind, may be referred to as coming within a category of locomotives. Such engines have to be very small, with small wheels, and for use in towns must be free from noise and smoke. They are made with vertical boilers, and with cylinders either vertical or horizontal. Some of the engines are on separate carriages, and, like the locomotive, haul **Engines for tramcars.** *See Chap. XII., Part I.* **Locomotive cars.**

the tramcar and others form part of the tramcar itself. The latter plan has been (1879–80) applied with success for the suburban lines

Steam cars.

of railways where most of the trains are hauled by ordinary locomotives. Very often in the vicinity of large towns there is a local omnibus traffic for which frequent trains are required, but too small to utilise profitably an ordinary locomotive and numerous carriages. To meet this kind of traffic, long cars holding about 40 people inside and 40 on the roof are used, the carriage being carried at each end on a 4-wheel truck, one of them by the locomotive. The truck with the engine can be immediately separated from the car when repairs are needed to it, and a fresh engine attached, so that the car is not rendered idle. A steam car employed in this way has the great advantage over one on a town tramway, that it runs upon the ordinary raised rails of a railway which are cleaner and in better order, and having no obstruction, as in streets, a considerable speed is attainable. The steam cars cost about £1,400.



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See TRAMWAYS *in Part I.*

Locomotives propelled by compressed air.

Besides the locomotives described in the preceding pages, there are special kinds which do not come within the class of railway engines. Thus there are locomotives propelled by compressed air instead of by steam. These engines have been generally confined to mines, but in an improved form they are likely to be adopted for long tunnels, street railways in towns, and wherever the use of steam is undesirable. It is usual to compress the air by a stationary engine to a density of from 70 to 100 atmospheres, to store the air, which has thus a pressure of 1,000 to 1,500 lbs. per sq. inch, in a container on the locomotive made strong enough for the purpose. The compound system of cylinders is found best to utilise the air pressure; two or more air cylinders of different diameters are employed, the high-pressure air being admitted first to the smallest cylinder, the exhaust entering a second cylinder, and so on to a larger piston as the air becomes more diluted. The experience in rock-boring machines, which has led to improvements in the apparatus for compressing, storing, and applying air, will be available for locomotives also.

See page 94.

See page 91. Also ROCK-DRILLS.

Rolling stock.

Rolling-stock is the general term by which locomotives, carriages, and wagons of whatever kind are classed in distinction to the fixed equipment of the line; and locomotives have been described in the preceding pages. But just as the strength and dimensions of the permanent-way are to a large extent determined by the kind of locomotive which is to run upon it, so has the locomotive to be made

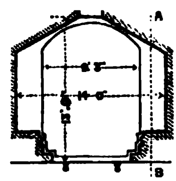
suitable for the haulage of the trains, and therefore the kind of carriages which the traffic is likely to demand is a point to be considered at an early stage in the inception of a railway project. Of course, if the railway has already been made, or if there be not free scope for choice because of the difficulties in the construction of the road, or for other reasons, the process must to some extent be reversed, and these exigencies be held in view in designing the rolling-stock.

See Chap. IV., Part I.

Carriages must accord with existing stock.

If a railway be projected merely as a branch or extension of an existing line, or even if an entirely new railway be constructed in a district so supplied with railways that the new line will contribute only a small proportion to the general interchange of traffic, then the preference should be given to carriages like those already in use, unless there be very important reasons for alteration. Every railway has its standard "loading-gauge," indicating the dimensions which will allow safe passage through existing bridges, or past station platforms and cranes. The diagram shows such a loading-gauge of a kind customary on English railways, to represent the outline of maximum load and the outline of minimum structure for a single line, the dotted line A B showing the centre of the "six-foot," if there is a double line. It is obvious, therefore, that there are certain leading dimensions in rolling-stock which, when once established, become perpetuated, and can only be altered with great inconvenience. There must also be exact uniformity in the width between buffers, and in the height of the buffers and draw-hooks from the rails. And while conformity in these respects is absolutely essential, there are other details where uniformity is a great convenience; so that if, for instance, a spring, draw-bar, buffer, axle-box, wheel, or axle be damaged when the vehicle is on a neighbouring line, or far from its proper repairing-shop, a new part can be readily supplied and adjusted on the spot without delay. Subject to these considerations, it will generally be found expedient, for the saving of trouble and expense, to utilise existing patterns of those parts or fittings which are staple articles of manufacture. It is only in the case of railways in a new district or country that new designs and standard patterns for all the fittings and equipment can be established with advantage. In such cases existing designs should be adopted only when the circumstances are sufficiently similar and the results have been proved by experience to be satisfactory.

Loading-gauge.



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Established sizes.

Uniformity of parts.

Standard patterns.

Designing of rolling-stock.

In the designing of rolling-stock, the principal points to be borne in mind are those which promote the safe and cheap working of the

traffic; and cheapness in the purchase price should be sought only when these more important conditions are ensured. The expenditure which unsuitable or insufficient carriages cause in the working of a railway soon outweighs the apparent saving which may have been so obtained. The points of principal importance are as follows:—

Points to be considered.

Form and size.

1. To design the vehicles of such form and dimensions as will be suitable for the passengers or merchandize to be carried, and as will require the minimum of labour in the marshalling, loading, and unloading.

Strength.

2. Suitability of the rolling-stock to form part of a train and to endure the shocks and strains of running, with due regard to the expenses of maintaining and repairing the stock.

Permanent-way.

3. The effect which the proposed rolling-stock will have upon the permanent-way and on the cost of its maintenance.

Haulage.

4. The cost of haulage.

Permanent-way, rolling-stock, and traffic considered together.

The above conditions have to be considered together, but they are to some extent conflicting, and, according to the circumstances of each particular case, certain points must be subordinated to others of more importance. It is only, however, by giving full weight to the various exigencies of the case, and by full accord between the road engineer, locomotive engineer, and traffic manager that the most suitable designs can be arrived at. The foregoing remarks are applicable to rolling-stock of all kinds, and are common alike to passenger carriages and goods wagons. But in regard to the purpose in view, and the manner of fulfilling it, the two kinds of vehicles need separate consideration.

Passenger carriages.

Suitable types.

Military needs.

American system.

In the designing of carriages for the conveyance of passengers, before entering on such details as depend on climate, or the kind of permanent-way and similar engineering considerations, it is necessary to decide the earlier question as to what type of vehicle will best suit the habits of the people, and in regard to this, social and even political considerations will be found to have weight. On many of the Continental railways, military considerations are allowed to prevail, both in regard to the course of the railways and the dimensions of the rolling-stock, and the convenience of ordinary travellers is studied only after these conditions have been satisfied. In Switzerland and the United States, the democratic influence is seen in the designs of the carriages as well as in the general management of the railway, everything being arranged for the convenience of the majority who travel; superior carriages and exceptional conveniences being added

only so far as they do not interfere with this primary purpose. In England, on the other hand, for a long time after railways were established, no attempt at comfort was made for any but first-class passengers, and both in regard to the times of departure and speed of trains, as well as to the construction of the carriages, actual discomfort and inconvenience were inflicted on all who travelled in any other than first-class carriages. It is now (1880), however, seen that after making a railway at vast cost, it is folly to so equip the carriages and arrange the service as to repel a large proportion of possible travellers, who not only afford the most remunerative traffic, but who, if a little expense and attention be paid for their convenience, may be greatly increased.

English system.

First-class alone considered.

Cheap traffic now encouraged.

It may be stated as an axiom that the fewer the kinds of carriages, the better for the cheap and profitable working of the railway; and while some variety of kind or class of carriage is necessary to meet the reasonable demands of the public, the variety caused by individual predilections of railway managers, or to obey some exceptional demands, are expensive and unnecessary. In England there are three classes of carriages on almost all the railways, and in some European countries and in India, even four classes. Where there are different races of people—as colonists and natives, or, as in India, where the caste customs of the natives have also to be considered—such great variety in the classes of carriages is sometimes justified.

Great variety undesirable.

Three classes as in England.

Four classes.

Carriages giving a longitudinal passage throughout the train are usual in America, and have been adopted with more or less modifications on numerous railways in Europe and elsewhere, but do not find favour generally in England, although they are followed in some of the British colonies. The freedom of movement for the passengers, the facility afforded for lavatories, stoves, refreshments, and other conveniences, and the passage from one carriage to another while travelling, alleviate the tedium of long journeys. Such carriages also allow the issue or collection of tickets during the journey, and in sparsely-peopled countries, or where it is desirable to save the cost of buildings, much of the work usually done at roadside stations may be performed by the conductor, who perambulates the carriages during the journey. On the other hand, the want of privacy—often of importance to ladies, children, and invalids—has retarded their popularity in Europe. There is the disadvantage also that the construction of the carriages allows doorways only at the extreme ends, and if there be many passengers, or if there be frequent stoppages at

American type of carriage.

Advantages.

See also page 261.

Disadvantages.

intermediate stations, the time occupied in the entrance and exit of passengers is inconveniently long. Moreover, in case of accident to the train, passengers have not the same opportunities for escape as in an English carriage. The American style of car is best suited for long-distance journeys occupying more than five hours, while the English fashion of separate compartments is, under most circumstances, greatly superior for short journeys or suburban traffic. In regard to the running of the carriages on the road, the arrangement of the wheels which is usual with the American cars can be adopted with carriages divided into compartments in the European manner.

English type best for short journeys.

Climate.

The exigencies of climate have an important bearing on the designs of carriages. In England the extremes of heat and cold last but a short time, and are considered sufficiently met by the provisions for excluding the wind and rain. But this is not sufficient elsewhere, and in Russia, Canada, and Scandinavia, extreme cold demands special kinds of doors and windows, stoves or more elaborate heating apparatus being essential in every class of carriage. In India and other tropical countries the extreme heat renders necessary sunshades, louvre blinds, and other means of ventilation; and double roofs are provided not only for all classes of passenger carriages, but for horse-boxes also. In such hot climates, special materials of construction have to be adopted; certain kinds of wood are found unsuitable; india-rubber, if used, has to be of special kinds; and the seats and upholstery have also to be different to those in temperate or cold climates. Railways have been so widely extended in every part of the world that a varied experience has accumulated in all these matters which should be utilised in new cases as they arise.

Extreme cold.

Extreme heat.

Special materials.

Gauge of railway.

The gauge of the railway is the primary or ruling circumstance which has to be considered in the dimensions of rolling-stock. The narrower the gauge the lower must be the centre of gravity of the carriages, and this limits greatly the scope of the designer; and though by proper arrangement it is found possible to make passenger carriages for the narrowest railways, yet the speed at which the carriages can run safely is less for narrow than for broad gauges; but, on the other hand, there is the advantage that carriages running on a narrow gauge can pass round sharper curves.

Determines many points.

Carriages made larger than formerly.

The passenger carriages made on the earlier railways were inconveniently low and narrow as compared with those made later, the dimensions of the old post-chaises having been apparently the standard first adopted. The experience gained in railway running

has shown that the longer, wider, and higher carriages, which are necessary to the comfort and convenience of passengers, can run safely without increasing the width of gauge. Thus, on the standard-gauge lines, carriages instead of being made as formerly 5 ft. 6 in. high from the floor to the centre of the roof, are now made of heights ranging from 6 ft. 8 in. to 8 ft.

Height increased.

Arrangement of wheels.

Whatever be the exact arrangement of passenger carriages, they are usually made of considerable length; and, if supported on a rigid wheel-base, as has been usual on European railways, they are jolted and strained while passing round curves; the permanent-way also being wrenched and loosened. The modern use of bogie-trucks greatly reduces these evils, and also facilitates the safe and smooth running of carriages over an ill-made or ill-kept road. In the application of bogie-trucks or other system of articulation to the under-frame or wheel-base of a passenger carriage, the designer is free from those limitations which, in the case of a locomotive, are caused by the connections of the working parts; and this greater scope has led to various modifications of the ordinary bogie-truck which are likely to prove useful.

Bogie trucks.

See page 276.

Materials.

Both in Great Britain and America, carriages of all kinds are almost invariably built of carefully-selected timber, iron being only used to bind the mass together and for purposes where its use is unavoidable. If the strains to which the various parts are subjected could be exactly defined, iron or wood could be arranged suitably to meet them; but the strains are too various. On European railways it has been found that the cost of maintenance for a term of years is greater for iron under-frames than for wooden ones; but for carriages built in England for use in India and other tropical climates the carriages are made almost exclusively with iron under-frames. But unless it is very skilfully disposed, the use of iron entails greater weight than wood, and the carriages when running at high speed have proved very noisy; but this is now to a large extent modified by the interposition of rubber cushion-springs between the iron under-frames and the wooden bodies. On the Continent, iron or steel is not only frequently used for the under-frames, but also for the panelling of the body, the framework of the latter being of wood.

Iron and wood.

Underframes.

Wheels.

The wheels of railway carriages and wagons are made in various ways. On the earlier tram-roads and railways the wheels were of cast-iron, but these proved unsuitable and unsafe for quick running or heavy traffic, and have consequently in England been superseded

Cast-iron and wrought-iron.

on all passenger lines by wheels made wholly or partly of wrought-iron or steel. In some, the centre or skeleton of the wheel is of wrought-iron, but in wagons the nave is of cast-iron, while the spokes and other parts of the centre are always of wrought-iron. But whatever the arrangement of these compound wheels, the tires are always made in a separate piece, either of wrought-iron or (to a growing extent since 1870) of steel, the wheel being turned and the tire bored with extreme accuracy to ensure a tight fit. There are various ways of fastening the tires, but for safety in quick running it is sought to avoid weakening the tire by holes made in it for bolts or rivets. As accidents have frequently been caused by tires breaking and leaving the wheel, it is endeavoured in the manufacture of wheels for passenger carriages so to attach the tire as to prevent it coming off even if broken into several pieces. This is ensured in the Mansell wheel, which, though more expensive than other kinds, is in the almost universal opinion of English engineers, the best for passenger carriages. In it the tire is ingeniously held by side plates or rings, which serve also to hold together the body of the wheel, which is composed of solid teak-wood segments tightly wedged together between the nave and the periphery, to the former of which they are bolted. Wheels of this sort run more freely than those in which the spokes are open to the wind; they are also less noisy and stir up less dust. But the Mansell and other similar modes of fastening can be applied also to spoke wheels as well as to those with wooden centres, some engineers considering the latter unsuitable for brake carriages, as the centre has a tendency to turn when the brake is applied to the tire. But while, in England, railway wheels are made in the various ways described above, in the United States solid cast-iron wheels are used almost universally. Made of high-quality cast-iron, the risk of brittleness is reduced by a softening or partial annealing, and the tread is rendered harder than steel by being cast in an iron mould or chill. These wheels are used, not only for wagons and carriages, but also for locomotives, though they are becoming discarded for driving wheels. But, wherever used, they are much cheaper than English-made wheels, and form one of the numerous points of difference which have to be considered in comparing the prices and quality of English and American rolling-stock. The preference of English engineers for wrought-iron or steel is partly owing to the fact that chilled cast-iron wheels have never become a staple article of manufacture and are not readily obtainable, but more particularly because

Steel tires.

Fastening of tires.

Mansell wheels.

Advantages.

Effect of brakes on wheels.

Chilled cast-iron wheels.

See page 278.

Not used in England.

such wheels (the chilled surface not being turned) are not absolutely round, and this defect, though of slight importance with the bogie-truck arrangement of wheels and moderate speeds usual in America, would be inadmissible on a rigid wheel-base or for high speeds. Moreover, the hardened part, which is not of great thickness, cannot be renewed by a new tire when worn out.

Wheels and axles. **Prices.** Wheels and axles are generally sold to carriage builders and others by the set of two pairs. The price ranges for spoke wheels with iron tires for wagons from £15 to £20 per set, and for passenger carriages from £20 to £30 per set, or with Bessemer-steel tires from £22 to £32; while Mansell wheels with wooden centres and complete with Bessemer-steel tires and axles, cost from £30 to £45 per set.

Axle-boxes. Axle-boxes are always fitted with brass bearings and are also usually sold per set of four. They range in price from £3 per set for those suitable for wagons, up to £6 per set for the more elaborate oil-boxes for passenger carriages. **Oil or grease lubrication.** Lubrication by oil is superseding that by grease, the axle-box being provided with a well-fitting dust-shield of leather or vulcanite and with suitable spring lubricating pads. If the axle-boxes are properly made and if good oil be used, the friction during running is much less than is the case with grease. All the above prices are for standard (4 ft. 8½ in.) gauge vehicles.

Light and ventilation. Other modern improvements in carriages have been in the direction of better light and ventilation. High omnibus roofs have been introduced on several English lines, and more window area provided. Different systems of using illuminating gas in a portable form have been tried, and seem likely to supersede the simple but inefficient oil lamps, which are dirty and costly.

Increased weight of carriages. The enlargement of the carriages and the various other alterations above referred to, have considerably increased the weight, so that even allowing for the greater number of passengers which large modern carriages can convey, the weight of the carriage bears a larger proportion to that of the passengers carried than formerly. Against the conveniences obtained have therefore to be set the enhanced cost **Disadvantages.** of the carriages, the greater expense of haulage, and the wear and tear upon the road; the latter being to some extent counterbalanced by the improved elasticity of the springs. The resistance at a high speed is augmented more by the greater size and wind surface than by the increased weight. On inclines, the weight is the important factor.

Carriages for use in the country of manufacture are almost invari-

The purchase of carriages. ably purchased complete, that is to say, although various trades are concerned and no carriage-builder makes all the parts, it is considered inexpedient to divide the purchase; and the responsibility for the whole is put upon the builder. For exportation also, complete carriages are generally purchased, for now that the principal carriage-builders make wheels and axles, the custom of making separate contracts for these parts is less frequent than formerly. But for the maintenance of rolling-stock it is often found advantageous to make separate contracts for the various parts, a usual division being: (1) **Contracts for separate parts.** wheels and axles; (2) axle-boxes fitted complete; (3) buffer-guides, and other castings; (4) bearing and other steel springs; (5) wrought-iron forgings, such as buffers, draw-hooks, knees, bolts, straps, and brake-work; (6) india-rubber springs; (7) upholstery trimmings; (8) lamps; (9) door-handles, and other mountings or fittings. In cases such as these, the body of the carriage may be either made in the importing country from indigenous timber or the wood-work may be also sent out in pieces. If all the wood-work is imported, the whole carriage should be fitted up complete in the country of **Packing for shipment.** manufacture, and then taken to pieces and packed. Carriages can be specially designed for this, the floor, roof, and sides all *See page 35.* forming flat pieces of nearly similar size, fitting into one packing case; the ends and partitions going into another. While a systematic plan of this sort is necessary to ensure accuracy and completeness, the **Wood-work omitted from purchase.** wood-work can, if necessary, be made in the importing country, and the little deficiencies and unavoidable inexactitude of a mixed-structure **Smith's work.** be made good there. The smith's work is also sometimes made in countries which have to import most of their equipment, one complete **Precautions to ensure fitting.** set of forgings being sent out as a pattern. Special precautions are of course necessary to ensure the proper fitting together of parts bought from so many different makers, and it is usual to supply to all concerned those sample parts to which connection will eventually have *See page 287.* to be made. On most railways, standard patterns are kept of all the essential parts, and certain main dimensions are prescribed to which absolute uniformity is demanded.

Excluding exceptionally high or low prices which have occasionally prevailed, the following are approximately the prices of some leading types of carriages for standard-gauge railways during the ten years ending 1880.

Third-class carriages about 27 ft. long in five compartments, with seats for 50 passengers, mounted on four Mansell wheels with steel

tires, cost from £320 to £380 and weigh about 7½ tons. First-class carriages of the same total length, with similar wheels and under-frames, and differing only in having fewer compartments and more elaborate fittings, cost from £450 to £550. Composite carriages, about 30 ft. long on three pairs of wheels, and divided into different classes and a luggage compartment, cost from £450 to £550. The more modern carriages, 45 ft. to 55 ft. long, on two six-wheel bogie-trucks, cost from £700 to £900 for third-class, and £1,000 to £1,200, and even up to £1,400, for those composed of first and second class. The above prices are exclusive of the cost of packing for shipment, which, including the labour of subdivision, ranges from 4 to 6 per cent.

Approximate prices.

Long carriages on bogie trucks.

Narrow-gauge carriages cost less than those for standard-gauge railways, but rather more if estimated in proportion to their weight and the number of passengers carried. Thus, to take a few types of carriages for mètre gauge (which would apply generally to 3 ft. and 3 ft. 6 in. gauges also), a third-class carriage, 20 ft. long and 7 ft. wide, with 4 compartments, each carrying 8 passengers, and fitted with brakes, would cost from £175 to £230, and weigh about 5 tons; a second-class carriage of similar dimensions £200 to £250; a first-class carriage about 20 ft. long in 3 compartments £250 to £300. Smaller carriages for carrying 12 first-class or 18 third-class passengers would cost about one-fourth less than the above prices.

Cost of narrow-gauge carriages.

A proper choice or design of a railway carriage can only be made on the basis of full information—in the first place concerning the number and class of persons to be carried, and secondly in regard to the circumstances of the railway, to which all the rolling-stock must conform.

See page 302.

The weight and cost of railway carriages have been increased by the introduction of continuous brakes, and though these brakes have been at first confined to railways having busy traffic, their usefulness will probably lead to their adoption on lines not so circumstanced, especially on those having numerous or severe inclines. The various kinds of fluid or pressure brakes do not (1880) differ much in regard to weight or cost. With actuating apparatus on each carriage, and with brake blocks on each side of four wheels, the extra weight on a carriage ranges from 10 to 13 cwt., and the cost from £30 to £35 per carriage. The various systems of chain and other mechanical continuous brakes are less costly and slightly less weighty, but seldom so efficient.

Continuous brakes.

See also page 276.

Their weight and cost.

Goods wagons.

In the selection or design of *Railway Wagons* for the conveyance of *Merchandise*, it is even more important than in the case of passenger carriages that the existing rolling-stock on the same or on contiguous railways, or on those with which future connection is likely, should be considered, and uniformity on essential points be observed. But independently of this uniformity, which is necessary to through transit, different railway companies have their own rules in regard to strength and fitness, and will not allow wagons which do not reach their standard to run upon their lines. Such uniformity and conformity to rules allow of through transit of goods over several railways without change of vehicle, greatly promote traffic, and save time and expense. In the transport of merchandise, the circumstances to be considered are those already enumerated as common to all rolling-stock, but the proportions and the general conditions are very different to those of passenger carriages.

See page 287.

Standards of strength and fitness.

Essential to through traffic.

Shape and size of carriages.

One of the first points to be considered in the designing of goods wagons is their shape and size for the goods to be carried, and how best to carry the maximum quantity of what may be called paying load, with the minimum of non-paying load or tare of the truck itself. As the usual rates of carriage for minerals and merchandise range from ½d. to 2d. per ton per mile as compared with rates for passengers and their luggage, equivalent to from 6d. to 30d. per ton, it is evident that the proportion which the non-paying load bears to the paying load is of immensely greater importance for goods than passenger traffic, even taking into account the greater speed and therefore greater haulage cost of the latter. In countries where there is competition, or where low tariffs are prescribed by law, so closely does the cost touch upon the sums earned, that it is probable that much of the cheapest traffic—generally that of minerals—involves actual loss if the hauling and returning of empties or partially filled wagons be taken into account; and on all railways, and even where carriage rates are not cheapened by competition, very careful analysis of the varied expenses of a railway is necessary to ascertain the actual facts and to apportion to each kind of traffic the profit or loss accruing from it.

Tare weight.

Non-paying load.

Traffic carried under cost price.

Railway accounts analysed.

See page 67.

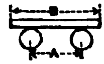
Width of wagons.

SEE LOADING-GAUGE, *page 287.*

The width of wagon is of course limited by the gauge of the railway and by the loading-gauge which bridges, tunnels, and other existing structures render necessary; and on standard-gauge railways it ranges from 7 ft. 6 in. (seldom exceeded) to 8 ft. 6 in. Wagons have to be narrower than passenger carriages, to allow for doors left open, loose

Limits of length.

tarpaulins, and other possible projections. In regard to length, while there is more room for variance in the design, turn-tables, weigh-bridges, and hydraulic lifts, when once established, limit the dimensions, while safety in running limits the length of wheel-base, and, with certain qualifications, the length of carriage also.



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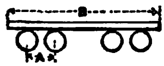
Length of wheel-base.

On English railways 8 ft. 6 in. is a usual length for the wheel-base, A, and it seldom exceeds 9 ft. The body of the wagon is seldom allowed to overhang more than 3 ft. at each end, and the total length, B, ranges from 14 ft. to 16 ft., though wagons for special purposes are occasionally made longer. Wagons of these moderate dimensions are convenient for marshalling and shunting, require turn-tables of small diameter, and can be made strongly with moderate weight. In the United States, while the advantages of a short wheel-base are, because of the less perfect roads, even more necessary than in England, it is allied with much longer wagons, for by the use of bogie-trucks the rigid wheel-base, A, is only about 5 ft., while a total length, B, of from 28 ft. to 33 ft. is obtained.



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Choice, how determined.

See page 290.

In the choice between these long wagons and those of English pattern, somewhat the same considerations prevail as determine the choice in passenger carriages, *i.e.*, the larger vehicles are generally preferable for long journeys. For instance, if large quantities of produce or merchandise have to be sent several hundreds of miles from or to a port, large wagons can be filled, involving less dead weight, fewer couplings, and making shorter trains than would smaller wagons of the same total carrying capacity. The longer the average journey, the less is the proportion of shunting and marshalling operations, and the saving in haulage cost which the long truck allows is less neutralized. Thus, while in America a wagon may run 1,000 miles and remain undisturbed in its place in the train, an English wagon may in the same number of miles make twenty trips, and require to be moved by a horse or by a hydraulic capstan, to descend and ascend a lift, and to be put on a turn-table once or twice on every trip. It will be seen, therefore, that large and small wagons have each their appropriate duty, and that neither type has an absolute superiority. Even in America, where long wagons are the rule, coal (which is there hauled a less average distance than is usual with produce) is generally carried in four-wheel wagons smaller than those in England for the same purpose. Not only the length of the journey, but speed and other circumstances have to be considered. Where there is a busy traffic, as on English trunk lines, the goods trains have to be con-

American system for long journeys.

Short wagons best for short runs.

Coal wagons.

tinually shunted to allow quick trains to pass, and even with this relief have to be run at a speed which is expensive, and only necessary to keep the line clear for passenger trains. Long or heavy wagons are not suitable for such treatment, and the construction of separate railways or duplicate lines for mineral and merchandise trains separate from those for passenger trains will, by allowing slower and less costly working of goods traffic, reduce the objections to large wagons.

Long wagons not suitable for frequent shunting.

In England, it is very usual to protect goods conveyed in open wagons by large tarpaulins thrown over the goods and firmly laced down to the sides and ends of the wagons. This method saves in weight, but the tarpaulins are apt to get lost, torn, and worn; and unless carefully tied, become loose and allow the wet to enter. If the first cost of the tarpaulins and their rapid wear and decay be taken into account, as well as the damage sustained by goods from the insufficient fastening of the tarpaulins, the alternative of closed wagons will generally prove the most economical. On American railways, where cheapness is much considered, covered wagons are preferred to tarpaulins.

Tarpaulins.

Are ineffective.

Within the limits prescribed by the foregoing considerations, there is still room for much diversity of design. If the goods to be carried were uniform in kind, and sufficient to fill the trucks, there would be little difficulty in arriving at a decision as to the best size. On a permanent-way strong enough for the passage of locomotives, there is such ample margin for the weight of trucks that, so far as the road is concerned, this circumstance seldom has to be considered, and the maximum is, as has been seen, rather determined by such secondary considerations as the weight which a horse can, in the operations of marshalling and shunting, not only draw, but start.

Diversity of design.

Weight for shunting.

In the case of mineral traffic, the haulage of the empty return wagons has also to be considered, and the comparison between paying and non-paying load has to be calculated on the basis of one journey of the former to two of the latter. It is of course the aim of railway managers to avoid such unremunerative hauling; but, though it can sometimes be reduced, it can seldom be avoided altogether. A favourable opportunity is found where there is an exchange of minerals. Thus, in an iron-making country, where the coal and iron mines are not contiguous, coal may be taken to the ore and ore brought to the coal, the wagons being thus employed in both direc-

Return journey.

Unremunerative haulage.

Exchange of minerals.

tions. In the iron districts of Northamptonshire blast furnaces have been established and are supplied with coal from more northern counties, the coal wagons taking back ore to the blast furnaces in the coal districts. This is a rare case, and in England generally, the coal traffic is too great to allow of return cargo for the wagons. And in most countries, even where there is a great interchange of traffic, the goods in the two are of a very different character, and the proportion of tare weight to be hauled different accordingly. Sometimes the difficulty is minimised by the direction of the gradients. Thus a railway for conveying minerals or metals from the interior of a country to the coast for shipment may be mostly downhill, and the lighter return loads may be appropriate to the return journey.

Coal and iron.

Haulage of tare.

Gradients.

It is obviously impossible to lay down a rule for the proportion of tare weight to paying load where the nature of the merchandise varies, and where, as in the stowage of a ship, bulk as well as weight limits the amount to be carried. And though, where there is a large staple trade of one particular kind, the wagons may be designed to suit it, they can seldom be the best for both journeys, and some compromise must be adopted. But with all these drawbacks, it is a reciprocal commerce which cheapens transport, and new trades, opening out new sources of revenue for railways, are generally developed where there is unrestricted interchange of commodities. Even where there is a large or staple traffic in light goods it is dangerous to make wagons of strength and weight proportionate only to such load, for there is always a risk that goods of other and heavier kinds may occasionally be placed in them on a return journey. And, however light the merchandise, the wagons may have to form part of a miscellaneous train, and must be strong enough to transmit the haulage force and to bear the shocks of running and shunting.

Load limited by bulk as well as weight.

See page 35.

Interchange of goods.

See page 59.

Risk of heavy goods in light wagons.

On all railways there must be various kinds of wagons for the different merchandise, but the fewer the types with which the traffic can be carried on, the more cheaply is the line worked; the inconveniences and expenses which great diversity causes being proportionately greater on a small railway than on a large one. The question is one for which no general rules can be established, but must be settled according to the circumstances of each case. On English railways the diversity of wagons is very great, but the evil is minimised where there is enough traffic for each kind of wagon. A less variety is necessary in Ireland, where the traffic is chiefly in manufactured goods, raw materials liable to damage by wet, and

Variety of wagons.

Diversity a cause of expense.

One type of wagon for various goods. cattle. One type of wagon can be used for various kinds of loads, because high cattle wagons can (after the compulsory cleaning they undergo) be utilised for bale or sack goods which can be effectually protected from damage or pilfering; and as the goods are valuable enough to bear a higher rate of carriage than cheaper goods on other railways, the extra tare weight of the covered wagons still allows a remunerative return for the haulage. **High-freight rates allow for tare.** On the other hand, when stone, pig-iron, or slates have to be carried, for which low-sided wagons are sufficient, the tare weight should be brought down to the lowest point which the safe working of the railway will permit. **Size and form, how determined.** In short, while the *size* of wagons depends principally on the length of the journey, so does the *form* depend on the nature of the goods to be conveyed.

Springs necessary on wagons. In the earlier days of railways it was considered unnecessary to furnish wagons with springs, but the effect on the permanent-way of heavily-loaded wagons without such alleviation of the shocks—especially during the quick running necessary to allow of numerous trains—soon rendered bearing-springs necessary. And on most railways spring buffers and spring draw-bars are also adopted. The improvements in goods wagons during the thirty years ending 1880, have however been slight compared with those in engines and carriages during the same period. **Improvements in wagons.** Improvements have been mainly in the direction of greater strength and durability, especially in those parts which have proved liable to sudden breakdown; while in the designing of details and in the material employed, facility for repairs is more considered than formerly.

Materials. Railway wagons are subjected to such severe shocks that the best and strongest materials should alone be used in their construction, the durability of the wagons and the cost of repairs depending also on the care with which the timber has been selected and seasoned. **Oak for framing.** English oak, North American white oak, and pitch-pine are the woods most used in Great Britain for the framing of wagons, but the sheeting, flooring, and roofs are usually made of Baltic redwood or, in cheap wagons, of American spruce. **Fir and spruce.** For tropical countries, teak is often used. **Teak for hot climates.** The substitution of iron for wood as a material for railway wagons has often been advocated, even when for passenger carriages it is considered inappropriate, and it has been tried in various ways. **Strains on wagons cannot be defined.** If the strains to which the various parts of a wagon are subjected could be clearly defined, the selection of material suited to each might perhaps be made with advantage.

But the shocks and strains are so varied and peculiar that no such accurate apportionment can be arrived at; and though iron or steel is for some of the parts and foundations of a wagon obviously the best, it cannot be generally applied with advantage, but iron and steel are gradually superseding timber for the under-frames, wood being still considered best for all above the floor-level. One principal objection to the use of iron or steel is in the difficulty of repairs, especially at places distant from the principal workshops, and it is found that accidents, which in the case of wooden wagons might be easily repaired, are difficult or impossible where iron or steel has been bent or distorted. Iron wagons are, therefore, on English and American railways, seldom made except for peculiar purposes, such as the conveyance of hot refuse from blast furnaces, or other cases where the contact of the materials carried is damaging to wood. The quality of the wheels and axles is of the greatest importance, for not only the term of endurance and cost of maintenance depend upon it, but the safety of an entire train is endangered if one defective wagon or wheel form part of it. On English railways, and on most of the colonial lines, the axles are generally made of steel, and are larger and better proportioned than formerly; the tires also are of steel, and are held to the wheels by various forms of fastening which avoid objectionable rivets through the tread of the tire. So much depends on the couplings, draw-bars, and hooks that they are generally made of iron much superior to that used in other parts of the wagon, so that they may afford the necessary strength without inordinate weight.

Iron and steel as materials.

Wood has proved easiest to repair.

Wheels and axles.

Steel tires and axles.

The principal railway companies generally present to the manufacturers from whom prices are invited very elaborate specifications of what is required, and though standards of size, kind, and quality may have been established, improvements are from time to time introduced. But on many of the smaller railways, and especially those distant from the place of manufacture, the wagon-builders are often invited to offer their own designs. Rolling-stock can be suitably designed only on the basis of full information on the following points; and it is of the greatest importance that the particulars furnished by the purchaser shall be full and explicit, as the vague and indefinite information often supplied, not only is interpreted differently by competing manufacturers and a proper comparison of prices hindered, but the stock when built may be unsuitable for its purpose. But if the railway is an entirely new one, where interchange of traffic with existing

Specification of wagons.

By purchaser. *See page 4.*

Or by manufacturer. *See page 11.*

Full particulars necessary.

See page 49.

Design and price, how determined. lines has not to be provided for, the points of uniformity need not be regarded.

Permanent-way. 1. The gauge of the railway, the section of the rail, and a description of the permanent-way.

The kind of goods. 2. The kind of goods to be carried, with special regard to the following circumstances:—

(*a*) Whether the wagons are always to be used for the same class of goods, such as coal or iron.

Classified. (*b*) If for miscellaneous traffic, a description of the different classes and some indication of the proportions of each.

Damage by weather. (*c*) Whether the goods will be of a kind liable to damage by weather.

Fragile goods. (*d*) Whether the goods will be of a fragile nature requiring special protection from damage in transit and during shunting.

Theft prevented. (*e*) Whether valuable goods liable to pilfering are to be carried, and if so, what system, if any, is adopted or proposed of bars, locks, or seals to prevent it.

(*f*) The maximum weight and bulk to be carried in each wagon.

Uniformity. 3. Points of uniformity with existing vehicles on the railway or on neighbouring lines which are necessary or expedient, such as:—

Width. (*g*) Whether one central or two side buffers are used, and if the latter, the width between the centres of buffers.

Height. (*h*) The height of the floor of the wagons from the rails.

(*j*) The height of the buffers and draw-hooks from the rails, and a pattern or drawing of the hook.

Loading-gauge. (*k*) A profile of the established loading-gauge.

Wheels and axles. (*l*) The kind and dimensions of wheels, axles, and axle-boxes.

Wheel-base. (*m*) The length of wheel-base usual or intended, and, if locking bars are used at points, the length of the bar.

Engine power. 4. The size and power of the heaviest engines likely to be used.

Weight and gradients. 5. The maximum weight of train of which the new rolling-stock is to form part, and the incline of the steepest or ruling gradient.

Brakes. 6. Whether any sidings are situated on steep inclines, rendering brakes on every wagon necessary.

Curves. 7. The sharpness of the curves on the railway.

Lubrication. 8. Whether oil or grease is used for lubrication.

Lamps. 9. The kind of oil used for lamps.

Climate. 10. The nature of the climate in regard to the following points:—

Heat. (*n*) Extremes of heat which may render necessary special kinds of roofs or ventilation.

Dust.

(*o*) Prevalent dust or dirt which may require special protection for the axle-bearings.

Cold.

(*p*) Cold which may render necessary stoves in the brake vans for use in frosty nights, or during the crossing of mountains.

Rain.

(*q*) Excessive rainfall.

Materials.

(*r*) Whether certain kinds of wood or other material have proved to be or are likely to be cheap, durable, or unsuitable.

Wagons made entire or in part.

11. Whether the wagons are to be made complete or only in part; if the latter, which parts, and the kind, shape, and material of the parts to be added afterwards.

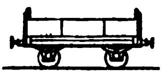
Wagons owned by railway.

The various improvements previously alluded to have increased the cost of rolling-stock, but the greater cost is justified by the easier running of the wagons, the less damage to the permanent-way, the greater security to the goods, and the less liability to failure, which is not only costly in itself but a cause of delay to other traffic.

Prices of English wagons.

The most usual types of wagons on the railways of Great Britain and their prices may be tabulated as under :—

	Approximate prices.	Average weight in tons.
Low-sided (sides 12 in. high) for ironwork or pig-iron	£60 to £70	4 to 4½
Medium (sides 36 in. high) the most usual in Great Britain (Fig. 151)...	65 „ 75	4½ „ 5
High sided (sides 48 in. high) for sack, bale, or bulky goods	70 „ 80	4½ „ 5
Covered for valuable goods (Fig. 152) ...	90 „ 100	6 „ 6½
Cattle wagons	95 „ 110	6½ „ 7
Salt wagons	85 „ 95	5 „ 6
Timber trucks (Fig. 153)	70 „ 80	4½ „ 6
Special trucks for large boilers	200 „ 300	12 „ 20
Goods brake-vans weighted with cast-iron ...	120 „ 200	10 „ 12



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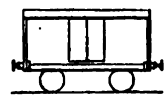

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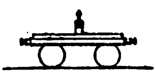

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Narrow-gauge wagons.

For narrow-gauge railways of which those of 3 ft., 3 ft. 3⅜ in. (mètre), and 3 ft. 6 in. may be included together, goods wagons will generally weigh, cost, and carry from 20 to 40 per cent. less than those of similar type of the standard gauge. But when the traffic is so little that one or few trains per day on a standard-gauge railway would carry it all, it may be found more convenient to run more frequent, because lighter and smaller, trains of a narrower gauge.

Wagons for little railways.

Wagons for little railways between 2 ft. and 3 ft. gauge cost from

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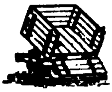

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£30 to £50; but on small-gauge portable railways, such as already described, for plantations, mines, or farms, or for contractors' purposes, where earth-tipping wagons are needed of very small gauge, steel or iron wagons, weighing from 4 to 12 cwt., and without springs, can be purchased for from £7 to £15; and if the underframe with wheels are alone purchased, for the addition afterwards of wooden bodies, these prices are diminished by about one-fourth.

Contractors' wagons.

Contractors' wagons (standard-gauge) made of wood, with wrought-iron axles and cast-iron wheels, but without springs, holding from 80 to 100 cubic feet, and arranged for tipping end or sideways, cost from £15 to £25, and weigh from 30 cwt. to 50 cwt.

Private wagons for coal, coke, salt.

Wagons owned by railway.

In certain staple trades, such as the coal, coke, and salt trades, the mine-owners and merchants use their own wagons, but for general merchandise it is the almost universal custom on railways that the wagons form part of the general property of the railway, although when railways were first established, the use of the railway by private carriers using their own wagons and locomotives was contemplated. There are different opinions as to the expediency of this system. In the one case, the railway companies are saved the great capital outlay involved in the ownership of numerous wagons, many of which are liable to be idle by depressed or fluctuating trades, and the private owner is more likely to have at command a proper number of suitable wagons. On the other hand, although railway companies subject all wagons to a careful examination in regard to strength and fitness before allowing them to run upon their lines, it is impossible to measure the quality and strength of the material of which the wagons are made, and accidents are caused by wagons of inferior kind forming part of a miscellaneous train. The wagons of private owners are often bought too cheaply, or are made by makers with insufficient plant and capital; such wagons are of inferior strength and fail oftener than those belonging to railway companies. It is also impossible to ensure that uniformity of size and interchangeability of parts which cheapen not only the purchase-price but the cost of repairs when wagons of many different owners run together. Moreover, much time and money are expended by railway companies in the sorting of trains and shunting them on sidings in order to send back the proper wagons to each owner, a labour which would be avoided if the wagons were common to all.

Systems of ownership compared.

Strength of wagons examined.

Private wagons sometimes inferior.

Sorting of wagons.

As a railway company can generally borrow money at a cheaper rate than most manufacturers, it is obviously cheaper for them to own

the rolling-stock, the interest on the cost being more than repaid by the higher freights received, as compared with those on goods carried on private wagons. But apart from the question of ownership is that of manufacture; and the railway companies can with advantage purchase rolling-stock from private builders, who—chosen by and supervised by the railway companies—can work as well and more cheaply; the tendency of railway companies to establish large factories for making as well as repairing rolling-stock being of doubtful expediency.

Railway companies can buy, cheaper than make, wagons.

The purchase of rolling-stock is often beyond the means not only of private persons but of railway companies, and traffic is hindered and the development of a railway retarded by the want of capital for this purpose. The advantage and profit of having sufficient and suitable rolling-stock are, however, so obvious, that separate associations of capitalists have been formed for supplying it; and wagons are let out for hire to private persons and railway companies. This business of letting out for hire is carried on partly by wagon-builders, who increase the number of their customers by asking in return for the wagons they supply rent only instead of purchase money, and partly by separate financial associations who buy from makers. The ownership of wagons supplied in this way is denoted by name-plates conspicuously affixed to the wagons. The owners generally undertake to maintain the wagons in repair during the period of hiring, and, besides the factories where they are built, have small workshops at the principal stations where the wagons congregate. Sometimes the rent merges into a purchase price, under the system known as "deferred payments," the ownership of the wagons passing to the hirers after a certain number of instalments have been paid.

Traffic hindered by insufficient rolling-stock.

Hiring of wagons.

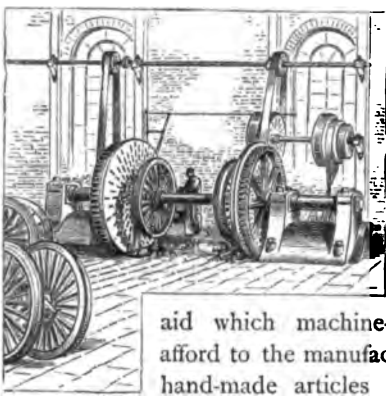
Wagons repaired by owners.

Purchase by deferred payments.

[*See also in Part I.*, RAILWAYS.]

CHAPTER XXIII.

MACHINE-TOOLS.



MACHINE-TOOL making is one of the most important of the subsidiary trades, which have accompanied and formed part of engineering science in every forward step. The adequate supply of steam-engines and machinery to all the various purposes of modern times is only rendered possible by the aid which machine-tools and automatic processes afford to the manufacturing engineer.

Machine-work better than hand-work.

However much hand-made articles may, in some branches of the arts, be considered superior to the machine-made article, the reverse is the case in most engineering operations, for in almost all cases the aid which the machine process affords is found to improve the quality, while it reduces the cost. The engineer and the tool-maker meet each other half-way; the one framing his design so that as many parts as possible can be operated on by machinery; and the other, year by year, contriving new machines to supersede hand-labour.

Labour saved to the workman.

The artizan instead of having as formerly, by his own sheer force, to cut the metals on which he works, can now apply his skill to the higher function of setting out his work and superintending the machines which obey his will. The mere tending of the machines and the adjustment of the cutting-tools can be performed by an ordinary workman, and the amount of finished

work which a certain expenditure of time, money, and labour will produce, is immensely increased, to the great advantage of the community. Wages saved to the employer.

The earlier inventors evolved the principles of the machine-tools—such as the action of the planing-machine, slide-rests, screw-cutting gear—and for many years little improvement was effected on the forms adopted by the original makers. But ingenuity has since been directed to improvement in detail, and has been stimulated by the assistance rendered by the users, who, being themselves engineers or skilled workmen, have been able, more easily than could users of other machinery, to invent or suggest new contrivances. As applicable to engineers' tools generally, the following have been the most important of such improvements :— Early inventions. Improved in detail.

The framework is better designed, and one piece or casting is, wherever possible, substituted for numerous parts bolted together; and a hollow section, which affords greater strength and stiffness, is preferred to the **H**, **T**, or **X** section, formerly adopted. Steel and malleable cast-iron are substituted for cast-iron in parts exposed to torsion or percussive strains; spindles are made of steel instead of wrought-iron; hardened steel bushes, which are long-enduring and can be replaced, are used instead of unlined bearings, which were bushed only when worn; contrivances for taking up the wear are more usually supplied; and the overhead gear is of better form, and fitted with more powerful cone-pulleys than formerly. Greater facilities for attaching the work to the machine are provided, which lessen considerably that expenditure of time and money in fixing, adjusting, and detaching the work which often exceeds the expense in the actual operation of the machine. The greatly-extended use of steel as a material for engineering structures, and the stronger tools which may be necessary for operating on it, will doubtless tend to further modifications and improvements. While in all engineers' work accurate fitting, true surfaces, and exact lines are desirable, these qualities are specially necessary in machine-tools which reproduce and multiply, in the work to which they are applied, the good or bad workmanship by which they themselves were constructed. Better framing. Steel parts. Bearings. Pulleys. Attachments. *See page 151.* Accurate fitting essential.

Machine-tools for engineers may be broadly classified as follows:— Engineers' tools classified.

1. Machine-tools for the makers of stationary, marine, and locomotive engines, and work of a similar character.

2. Machine-tools for iron ship-builders, bridge and girder makers, tank and gas-holder makers.

3. Smithy tools, including steam-hammers and hydraulic forging-machines.

Other tools omitted. The special machines and appliances for iron and steel making, for rifled ordnance and small-arms manufacture, for the cutting and manipulating of wood, fibres, fabrics, and leather, all of which might be classed as tools, may be considered outside a strictly-defined category of engineers' tools, and are therefore not further alluded to here. Each of the divisions might again be subdivided, and generally according to the weight and strength of the machines, and great variety of special tools included. It is, however, here only intended to give the leading types of machine-tools, although incidentally variations or adaptation for particular purposes will be alluded to.

For the present purpose, however, the most convenient classification of machine-tools may be made according to their kind as follows:—

Machine-tools enumerated. Lathes, Drilling-machines, Boring-mills, Planing-machines, Slotting-machines, Shaping-machines, Milling-machines, Emery-machines, Screwing-machines, Punching and Shearing-machines, Riveting-machines, Plate-Bending machines; Smithy Tools, Steam-hammers, Hydraulic Forging-machines.

Lathes. *Lathes* stand first in order of importance among machine-tools; and the various uses to which lathes are applied have greatly increased. It may indeed be asserted, in regard to steam-engines and general machinery, that the cost of workmanship depends mainly on the proportion of the work which can be performed by the lathe; and for this reason, engines, and machines of all kinds—especially those which are made in large numbers alike—have their parts specially designed to this end. **Lathes classified.** Lathes may be classified generally as ordinary *Slide-lathes*, where the cutting is principally external and parallel, or nearly so, to the axis, and in which the sliding of the rest may or may not be self-acting; *Screw-cutting lathes*, in which the slide-rest is not only self-acting but which can be made to advance automatically at any desired speed parallel to the revolving shaft; *Surfacing-lathes* in which the slide-rest is self-acting not only for sliding along but across the face-plate, these lathes being mostly used for turning across the axis and for internal turning or boring; *Hand-lathes* for small and light operations, worked either by foot-treadle or by steam-power, in which the tool is held and moved by the workman instead of in a slide-rest; *Copying-lathes* which reproduce, more or less automatically, a copy or pattern presented for

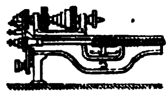
imitation; *Multiple-lathes*, where two or more similar articles placed parallel to each other are operated on simultaneously by their respective tools, all guided and moved by the same power. There are numerous other lathes made for special purposes, such as lathes for railway-wheels, for oval turning, spherical turning, engine-turning.

Slide-lathes.

The size or capacity of a *Slide-lathe* is stated according to that distance from the centre of the mandril-head to the face of the bed which determines the diameter of the article which can be admitted; and lathes are designated accordingly as 10-in. lathes (admitting an article 20 inches in diameter), 12-in. lathes, and so on. Among the various modern improvements in slide-lathes, increased strength has been given to the mandril-head or fixed head-stock, and the fixing of the work in place has been expedited by well-contrived chucks. Self-acting or automatic feeds for moving the tool-holding slide-rest have been much improved by being made more direct-acting; and special tool-holders and shapes of tool-steel save time in adjusting and working.

Improvements.

Used as surfacing-lathes.



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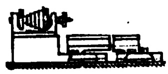
Gap-lathes.



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Sliding-gap lathes.

Slide-lathes can of course be used as surfacing-lathes, so far as the clearance space from the centre to the bed allows room for articles of a certain diameter, and this space is increased by a gap in the bed at or near the head-stock. One of the modern improvements in connection with *Gap-lathes*, as they are called, is the making of this gap to open and shut with a screw (the bed moving back on a planed foundation-plate), so that articles of greater breadth than in a lathe without this contrivance can be inserted. Such machines are known in England as sliding-gap or break lathes. The sliding-bed also allows the longitudinal distance between the mandril-head of the lathe to be increased, so as to admit shafts or other articles to be turned, of a greater length than would otherwise be possible. For 16-in. lathes and under, it is usual to have a fixed gap, but for larger sizes the sliding gap is preferable, as the gap can be closed up to allow of the slide-rest being brought near to the face-plate for heavy work of a diameter too small to need the gap. It is especially necessary that the foundation shall be not only true and stable for a sliding-gap lathe, but that the bed shall be of ample weight to make up for its loss of strength in not being self-contained. In some of these lathes, the mandril-head slides on a bed, and so alters the width of the gap; in others, the part of the bed on which the loose head-stock (called sometimes the poppet-head) works, moves to or from the mandril-head.

Different kinds.

turned; whether the work is of a heavy or light kind; and the class of work or trade on which the machinery is to be employed. Although this capacity or size and length of the bed are the main dimensions by which the lathe is designated, these particulars do not alone allow the proper appraisement of value, for if the height of the centre be increased (so as to increase the nominal capacity of the lathe) without increasing the strength of the parts—as in the competition of trade is not unfrequently done for cheapness—the bed, head-stock, and other important parts will not be strong enough for the additional weight which the size of the article throws upon them, and the tool will have to work at an unprofitably slow speed or depth of cut, or the lathe will be unduly strained or break.

Strength must accord with size.

See page 309.

Wheel-turning lathes.

See VIGNETTE, *page 306.*

See page 265.

Wheel-lathes are used for turning and boring railway-wheels, and are generally made with two slide-rests to operate at the same time on a pair of wheels fixed to an axle. Sometimes there are even four slide-rests, so that a tool can operate at the same time on each side of each wheel. The face-plates can be made to revolve at the same or at different speeds, so that a wheel may be turned on one, while another wheel is bored on the other. As the gauge and diameter of railway-wheels vary only within moderate limits, every part of the machine can be made exactly for the purpose in view. Lathes of this kind are also employed as surfacing-lathes for boring out the tire for the wheel and the hole for the axle. Wheel-lathes cost from £250 to £1,000, and weigh from 8 to 40 tons, the heavier and more expensive kinds being very powerful for turning large locomotive wheels.

Cost.

Multiple-lathes.

Multiple-lathes have two or more parallel spindles, and are made either as turning-lathes or surfacing-lathes. They are chiefly used in those trades where large numbers of articles have to be made precisely alike. Thus in the manufacturing of small steam-engines or pumps, three cylinders or three pump-barrels can be bored, faced, or turned at one operation; or screw-cutting effected on three rods. Lathes of this sort may be regarded as special tools; they are seldom made except for some particular purpose, for which they are specially designed, and cost more than double the price of ordinary lathes.

Copying-lathes.

Copying-lathes are those in which the shape is given to the article operated on, by coupling the cutting-tool to a blunt feeler tool, which follows the shape of an iron or steel pattern revolving on a parallel axis to that of the article to be turned. These lathes are mostly used for turning in wood, oval hammer-shafts, wheel-spokes, and similar articles.

Special lathes.

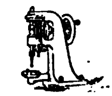
Special lathes are made for the various smaller industries which are subsidiary to the engineering trades. Lathes for brass-finishers are generally made of very simple construction, with the mandril revolving at a higher speed than is usual in the turning of iron and steel. Lathes of an ingenious and rather complicated kind are made, in which brass-work can be turned and bored either parallel or taper, faced and screwed, without removing or re-fixing the work. Articles can be finished in these lathes to gauge, and interchangeable, for less cost than the less perfect work done by the old-fashioned methods. Lathes for oval, spiral, and other ornamental work are also made, but are not generally employed in engineers' workshops.

Brass-finishers' lathes.

Drilling-machines.

Classified.

The *Drilling-machine*, as one of the rudimentary and necessary tools of the metal-worker, was, like the lathe, in use long before the introduction of steam-power. The different kinds may be classed as *bench*, *wall*, *pillar*, and *radial* drills, besides which there are horizontal and other special kinds; the choice among these different machines depending mainly on the size, shape, and weight of the article to be operated on. *Bench-drills* are small machines which can be bolted down to a work-bench and driven either by hand or power. Hand-machines cost from £5 to £10, and are often used in small factories where there is no steam-power available, or on temporary works. Bench-machines driven by power cost from £8 to £40.



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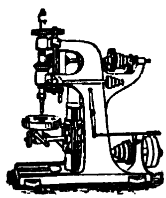
Bench-drill.

Wall-drill.

Wall drilling-machines can be used with advantage for articles of moderate weight and size, so that one man can move them about at the machine, and by its attachment to the wall a machine of this kind is more easily and cheaply steadied than a pillar-drill or self-contained machine; and it occupies less room in the work-shop. But when articles of wide or irregular shape have to be drilled, the wall would in many cases prove an obstruction, by hindering the article from being turned about and brought into position under the drill. It is for cases of this sort that the self-contained *Pillar-drill* is useful, as there is more room around the machine within which to move or adjust the article. The distance from the edge of a casting or other article at which a hole can be drilled, obviously is limited by the distance which the drill projects from the framework of the machine, and this "depth of gap" in a wall or pillar-drill is one of the leading points deciding the capacity and usefulness of the machine. The wall-drill and pillar-drill are generally similar in other points than that which their name signifies, and modern improve-



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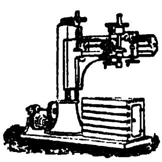
Pillar-drill.

ments in detail have been made in both alike. Better gearing, adjusting-tables, facilities for attaching the article to be drilled, changes of speed and automatic feed in the advancing cutting motion of the drill, are the directions in which such machines have been improved, all these points acquiring greater importance as the diameter of the holes to be drilled becomes larger.

Capacity, how stated.

The capacity of a drill may be measured or stated according to the width or diameter of the article that the table of the machine will admit, the diameter and depth of the hole which it will drill, and the kind of gear. The size of hole that can be drilled determines most other points, such as the diameter of spindle, the size of the wheels, and the strength and stiffness of the framing to resist the upward thrust from the drill, and also whether single or treble gear is required. Drills of the kind just described are needed even in the smallest engineering factory. A wall-machine for holes up to $1\frac{1}{2}$ in. diameter costs from £20 to £40; one for holes up to 3 in. diameter, from £30 to £50; and larger sizes up to £100, the necessity for numerous parts and self-acting apparatus increasing with the size of the machine. The above prices include the driving-pulleys and apparatus by which the power is transmitted from the main shaft of the workshop to the particular machine. Pillar-drills, as self-contained machines without the advantage of the wall supports, cost generally from about 20 to 50 per cent. more than the wall-drills of like capacity.

Cost of drilling-machines.



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Radial drilling-machines.

The introduction of the *Radial* drilling-machine was a notable and valuable improvement in machine-tools. Till that time, large castings or other articles which were too wide for the gap of an ordinary drill or too heavy to be conveniently attached to such machines had to be drilled by hand; and in the case of heavy articles in which numerous holes had to be drilled, even if the size and weight did not forbid the use of the machine, the constant moving and adjustment under the drill for each hole was troublesome and expensive. In a radial machine the drill is operated from a projecting arm or jib which swings from the central column or standard of the machine, and within this arm the power is transmitted by a horizontal shaft to the frame containing the drill-spindle, and this shaft, having a continuous slot or key-groove cut in it, the bevel wheels (generally mitre or 45°) upon it can give motion equally at any point in its length to the wheels on the drill-spindle. The swinging arm is sometimes arranged to move vertically on the framing which carries it, the motion in this respect and

Method of working.

the transmission of power being effected on a vertical slotted shaft in the same manner as that just described for the horizontal shaft. Not only, however, does the far-reaching arm of the machine allow holes to be drilled at a distance from the edge of the article far greater than the gap of an ordinary machine would allow, but, as the drill can advance or recede along the whole length of the arm, and, when the arm is made to revolve, command any point within the radius, the machine is particularly useful in those cases where numerous holes have to be drilled in the same article, which remains stationary while the radiating arm moves; and the article having been once levelled, any number of holes can be drilled perfectly parallel without any further adjustment, a result which is hardly to be attained with any other machine. The mechanism of these drilling-machines has been greatly improved, the various movements of lifting or lowering the jib, of traversing the drill-spindle along the jib and of swinging the jib, being all controlled by the workman without his having to leave his place by the drill. **Advantages.** **Drill commands a large area.** **Improvements.**

In a radial drilling-machine it is obvious that there are great strains on the upright framing of the machine from the leverage of the overhanging arm and from the pressure of the drill transmitted through it, and accordingly the connection to the upright framing, while allowing easy movement, must be very firm. As the drilling of large holes is apt to cause vibration, it should be avoided at the extreme radius unless the jib is supported at the outer end as presently described. With some radial machines, large base-plates are provided for attaching the article to be drilled, but for operating on heavy castings the weight of the article itself resting on the ground affords sufficient stability against the action of the drill. The cost of radial drills varies according to the size and capacity of the machine, to the precise arrangements of the parts, and to the extra movements or accessory apparatus which may be needed, and, of course, also according to the degree of finish which different service demands or different makers provide. A machine for taking in an article 4 ft. high, and in which the drill commands a space of 4 ft. radius for drilling holes up to 4 in. diameter, costs from £100 to £140, while a machine with 6 ft. radius and for holes up to 6 in. diameter costs £200 to £250, such machines, for instance, being those suited for an average engineering works or locomotive factory. Radial machines fixed to the wall and commanding therefore only a semicircular area, cost about one-third less than the above. Much larger machines are, **Strong framing necessary.** **Vibration.** **Base-plate.** **Cost of radial drill.** **According to size.** **Large machines.**

however, constructed for use in marine-engine factories or wherever the articles to be drilled are of great size. The radial arms or jibs extend 12 ft., and when the drill is working at the end of the jib, the latter is supported by a standard temporarily fitted upon the bed-plate, and having within it a vertical groove within which the end of the jib can slide up and down. Machines of this sort cost from £400 to £500.

Jib doubly supported.

Horizontal drill.

Among the special drilling-machines contrived for particular purposes or trades those may be mentioned which drill holes in other than a vertical direction. The radial machine just described is sometimes made so that the drill-holder can be adjusted at any diagonal angle. Horizontal fixed machines also are made for drilling the flanges of pipes, cylinders, columns, and screw-piles which cannot conveniently be brought within the operation of a vertical drill.

Purpose.

Drill-posts.

Hand-braces.

Drilling has often to be performed in situations inaccessible to any of the machines just described, and in such cases it is usual to fix a "drill-post" or light frame on or near the article to be drilled, and by means of a ratchet or swing brace attached to the post to work by hand, such process, however, being tedious and expensive. The necessity for manual work of this kind has for the great majority of cases been rendered unnecessary, for by an ingenious invention the power from the main shaft of the workshop can be transmitted at any angle and to a varying distance to a drill-post where the drill (adjusted and controlled by the workman as with the ordinary hand-drill) operates with all the advantages of mechanical as compared with manual power. But the best application is that in which the drill-post is equipped somewhat like the arm of a radial drill with a traversing-screw and feed-gear, so that, when the post is clamped to the work, all the advantages of a drilling-machine are obtained. Instead of a belt, a hempen or cotton rope is used to transmit power to the machine, and the pulleys over which the rope runs being made to revolve on a swivelled frame, the running rope can be taken in any direction. The tightness of the rope necessary to transmit the power is obtained, not as with a belt by making and maintaining the rope of an exact length, but by suspending to it a weight. It will be seen, therefore, that according as the drill-post, with the power-receiving pulley round which the rope runs, is more or less distant from the power-giving pulley, the weight rises or falls, always putting a sufficient strain upon the rope. During the drilling of large holes the weight can be increased to prevent the rope slipping upon the pulley. A complete

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Portable drill.

Worked by rope. *See page 110.*

Rope kept taut by weight.

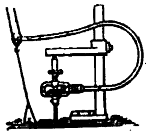
apparatus, including the drill-post with the necessary gear, costs from £35 to £50, the novelty consisting in the swivelled pulley-frame and suspended weight.

Prices.

Obstacles to machine-drilling.

The machine just described is of course only applicable in cases where no obstacle interposes between the power-giving shaft and the drill-post, although, if the occasion were of sufficient importance to warrant the construction of the necessary pulley-apparatus, the ropes need not move in one direct line, but might be conducted round corners. But it is obvious that there are many parts and corners of ironwork or machinery in course of construction where holes are needed quite inaccessible to such an apparatus, and hand-drilling seems the only resource. But by the use of "flexible shafts" power can be transmitted round corners in a manner which appears remarkable. It has been discovered that by a peculiar arrangement of spiral wires, held together in a tube or sheath of leather, a revolving motion can be transmitted a considerable distance with very little friction, even although the shaft or axis be turned or twisted in several directions. Thus, such a flexible shaft can be taken in at the man-hole of a boiler to a drill working at a remote corner, or to places as apparently inaccessible. The shaft is enveloped in leather and has somewhat the appearance of a flexible gas-pipe. The complete apparatus, including 8 ft. of shaft, cost from £10 to £30.

Hand-drilling.



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Flexible shaft.

Price.

Multiple drill.

Multiple drills (several drills on one machine operating at the same time) are employed where a large number of holes are required in regular order or sequence, such a multiplication of drills allowing not only a saving of expense but—unless a large number of machines were employed—a great saving in time also. Such cases occur, for instance, in wrought-iron girders, if drilled rivet-holes instead of punched holes be required. Boiler-plates in like manner afford opportunities for multiple drills; also the tube-plates of tubular boilers or surface-condensers. As in work of these kinds there are certain usual distances apart of the holes (from 3 in. to 6 in. apart, embracing those most usual and useful) there is repetition enough to render the construction of special tools profitable. Multiple drills have been designed in various ways, partly to meet varying necessities and partly because of differences in method. For girder-work the general arrangement resembles that of a planing-machine, the table on which the article to be drilled is placed, moving between a transverse framework carrying the drills. The drilling-spindles are generally ranged in line across the machine and are operated from

Where used.

For repetition work.

Machine described.

one shaft either by a screw and worm-wheels or by bevel gear. The precise methods of working differ considerably, and some machines offer more facilities than others for quickly adjusting or disengaging

Pitch of hole varied.

the drills. In all machines the pitch or distance apart of the holes can be varied within certain limits, the distance depending on the width of the tool-holder, the maximum distance being only limited by

Drilling of girder-plates.

the width between the standards. If, as in a girder-plate, six rows of holes have to be drilled to a pitch of 4 inches, six drills work side by side, and the moving table moves forward 4 inches from time to time. If a single row of holes only is required, as in a bar, then it is endeavoured to utilize as many drills as possible by placing numerous

Several plates drilled together.

bars side by side. Time is saved by placing numerous plates upon one another and drilling through all the thicknesses at one operation. In such a case one plate may with advantage be drilled first and placed at the top and used as a template or guide for the drill, no spacing or marking of the lower plates being then necessary. The drilling through numerous thicknesses not only increases the effective service of the machine but ensures accuracy of work where two or more plates have—as often happens in girder-work—to be riveted together, for, when each plate is drilled or punched separately, it is impossible, even with the greatest care, that the holes should absolutely coincide. Multiple drilling-machines may be driven by belting

Prices of multiple drills.

in the ordinary way, and such machines cost from £100 to £400 each, and weigh from 2 to 12 tons, but it is often convenient to make the machine independent of the general running shaft and to attach a small steam-engine to the machine; an additional cost being then incurred of about £50 exclusive of boiler.

Portable multiple drills.

Portable multiple drills have been devised for drilling the main booms or members of girders when erected in place, the various thicknesses of iron that have to be united not till then having been

For drilling girders in place.

placed together, so that the drills can pierce through all in the manner considered desirable for ensuring the desired coincidence of the holes. Drills of this sort to be serviceable must be strong, and they cost about £300, but have not been very widely adopted.

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Twist-drills.

The usefulness of a drilling-machine depends greatly upon the suitability of the drills which do the work. An useful accessory to drilling-machines of all kinds is afforded by the *Twist-drill*, which may be considered as one of the most valuable minor inventions which have been introduced in machine-tools. It is superior to the ordinary drill in that, instead of being smaller above its point, it is parallel its

entire length, and therefore it forms a correct guide for itself to bore a straight hole; it cuts out the substance as a shaving, which escapes through the spiral groove; and it maintains its diameter to the end. The twist-drills, however, demand special skill in their manufacture, and cannot, like ordinary drills, always be made by the users. It is essential that the drills shall be ground quite truly, and special grinding-machines are sometimes used for this purpose, a usual plan being to cut the spiral grooves with a milling-machine. It is also very important that the drills shall run truly, and to ensure this, the shanks of the drills are turned taper round to fit exactly into a conical socket-hole. By this arrangement the point of the drill revolves truly in the same axis as the spindle; the drill can be quickly put in and taken out of the machine; and drilling can be much more quickly performed than with ordinary drills. But while the twist-drills ensure quick and accurate drilling in the manufacture of such exact work as engines and machinery, some users find a simple drill, aided by a water jet, effective for such drilling as is required in girders or boiler-plates. These drills are of a form which allows the shavings of metal to escape, and by means of a small tube, a jet of water in fine spray is ejected on to and around the point of the drill. The water should have a pressure of not less than 50 lbs. per square inch, and if this be not obtainable from an existing water-main or pipe, a small pump (worked by the shafting of the drilling-machine itself) should be provided for the purpose.

Require skill in manufacture.

How made.

Drilling aided by pressure-water.

Gauges are almost entirely used for the best class of drilling, and the workman is no longer allowed to regulate the size of his drill and test its operation merely by the callipers and measuring-rule. Standard plug-gauges of great exactitude are obtainable and are specially essential where repetition or interchangeable parts are manufactured.

Holes drilled to gauge.

Standard plug-gauges.

Although holes may be drilled with great exactitude by the machines which have been described, other processes are necessary for a bore of large diameter, and also where large holes have not to penetrate right through the substance operated on. Much boring is effected on the chuck of a surface-lathe, and with a cutting-tool worked from an ordinary slide-rest the operation may be classed as internal turning, as the tool is stationary while the article to be bored revolves. Another kind of boring is that in which the article is fixed on the lathe-bed or boring-mill, and a mandril or boring-bar, held only at one end by the chuck, enters as far as needful, the mandril with a cutting-tool upon it travelling forward or the tool moving along the mandril

Boring on lathe chuck.

Boring by mandril bars in lathe.

by a self-acting arrangement. Such a method is useful for boring large or heavy castings which cannot conveniently be attached to a revolving chuck. Where however the hole passes right through the casting, it is better to use a boring-bar or mandril, supported at both ends; and so convenient and (for long bores) even necessary is this method that a hole right through the casting is sometimes made temporarily (and afterwards plugged up), even where the bored hole is limited only to a portion of the length. Resembling lathes in many respects, machines devoted to this special purpose are known

Boring-mills.

as *Boring-machines* or *Boring-mills*, and are used for boring out steam cylinders, pump-barrels, and other similar articles, the interiors of which, already approximately correct from the foundry-mould, have to be bored truly cylindrical, an operation more conveniently effected in a special machine than in an ordinary lathe, although the latter can be generally used if desired. Boring-machines range from 10 ft.

Usual sizes.

to 20 ft. long, and have a bed and head-stock somewhat like those of a lathe. The cylinder to be bored is adjusted on the bed-plate, to which it is firmly fixed, and the boring-bar or rod of the machine—in effect a large mandril—passes right through it. Upon the rod is a disc-shaped tool-holder with one or more projecting cutters, and as the bar

Mode of working.

revolves and the cutters operate, the disc is made to advance by a screw within the bar, till the cutters have bored out the entire length of the cylinder. The desired smoothness of surface is given either by a succession of operations or by placing two or more tools on the travelling disc, so that following close behind each other, two, or perhaps three, cuts are given at the same time. The boring of large cylinders sometimes occupies many days, and it is not

Continuous working.

unusual for the machine to be kept at work without any stoppage till the work is completed. In a boring-machine of the kind just described there is a longitudinal or "end-on" pressure of the bar against the head-stock, and sometimes during a heavy cut, the friction at the bearing place which receives the pressure of the bar is excessive, and is with difficulty kept cool and lubricated. Boring-machines

Prices.

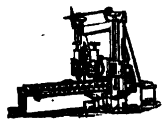
such as are used in an engineer's factory, range in price from £150

Vertical boring-machines.

to £300. Vertical machines of great power are employed to bore out large marine cylinders, and such machines cost more than horizontal machines.

Planing-machines.

The introduction of the *Planing-machine* was the first in a series of inventions which have since furnished to the manufacturing engineer



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entirely new kinds of tools. Till that period, surfacing which could not be performed in the lathe had to be laboriously effected with the chisel, file, and scraper; the facing of slide-valves and similar work by these means occupying much of the time of the best mechanics, and was even considered a leading test of their skill. In almost all planing-machines the tool is fixed, and the article to be planed travels, the motion being given to the table by a rack and pinion or by a screw, and the self-acting reversing movement by shifting the driving-belt from a forward-moving pulley to a backward-moving pulley. One of the most valuable improvements was the quickening of the return motion of the table when running back from the cut, as it is obviously unnecessary to move as slowly as when the tool is cutting; and the effective power of the planing-machine has been also increased by placing self-acting tool-boxes on each of the uprights of the framing, so that side-work can be performed at the same time as that on the table; this operation being possible, of course, only with certain kinds of work.

Mode of working.

Improvements.

Capacity, how stated.

The capacity of a planing-machine is stated by the dimensions, which are those of the width between the uprights, the height below the saddle, and the length of the tables; these dimensions, of course, determining the size of the article that can be brought within the operation of the machine. Thus a machine will be designated as 3 ft. by 3 ft. by 10 ft. long. The length of the article is not, however, bounded by the length of the table, as it can be made to overhang it, and if the length require it, be supported on rollers or trestles. To allow this, ample floor-space should be provided at each end of planing-machines, and if the workshop be otherwise too small, doors are generally provided so that long pieces can project beyond the workshop, thus giving full scope to the travelling table and its contents.

The planing of long pieces.

Usual sizes.

The great proportion of the planing-machines used in engineering factories range in size from 5 ft. long by 2 ft. wide by 2 ft. high, costing from £90 to £130, to those which are 14 ft. long by 5 ft. wide by 5 ft. high, costing from £500 to £600. Between these limits machines of all sizes can be obtained, although each maker has patterns of precise sizes which he prefers to supply. Sizes both smaller and larger than the above are occasionally made, but small planing-machines have been generally superseded by the more modern shaping-machines. Hand planing-machines are occasionally made for small workshops. It is most important that planing-machines be strongly and accurately made and solidly fixed, for any

Small planers superseded by shaping-machines.

Accuracy needed.

yielding or inequality will, of course, in any machine, cause the work to be untrue, and in a planing-machine these risks are increased by the number of jointings and moving parts which interpose between the levelled base of the machine and the cutting-tool.

See page 335.

Curved planing. Planing-machines can be adapted by special arrangements for concave or convex work, and by means of templates, which give a transverse or vertical movement to the tool as the table advances, varying curves can be produced; this latter operation being, for instance, often required in the planing of armour-plates for war-ships.

Plate-edge planing. A special kind of planing-machine is used by bridge-builders and others for cutting the edges of plates (several plates being generally clamped together and operated on at the same time), and these machines are generally made double-acting by "turn-over" tool-boxes, so that a tool is in operation both in the forward and backward movement. Machines of this sort can be made to plane plates as

Length. long as 20 ft, and it is of course necessary that the maximum sizes to be operated on be known to the maker; for if necessary, by a different construction of the machine, the plates can be then passed forward and a second 20 ft. planed in a continuous length. In some cases by this arrangement a shorter machine may be used for general work, as the effective length of the machine can be doubled

Prices. or trebled. A cost of from £150 to £250 will embrace the great

Wall machines. variety of plate-edge planing-machines. Wall planing-machines, having a vertical and horizontal movement for operating on large masses, are made chiefly for the use of marine engineers, but as in these machines the tools and not the article operated on travels, they may be more correctly classed as slotting or shaping machines; the space occupied is much less, and such tools are coming into general use.

Slotting-machines. *Slotting-machines* may be placed in the category of planing-machines, but unlike a planing machine, the tool and not the article to be operated on moves, and the movement is generally vertical. Slotting-machines can be either attached to the wall of the factory

How employed. or made independent: they are employed for cutting key-ways, or for cutting out masses of metal, as in crank-shafts; they are useful for many operations inaccessible to the drill, lathe, or planing-machine, and for certain purposes the balancing of the tool slide has been found a useful addition. They are made of all sizes up to the massive machines with a maximum stroke of 15 ft., used by marine

engineers, such machines costing sometimes as much as £2,000; but for ordinary engineer's work the cost of slotting-machines ranges from £50 to £500. Prices.

The *Shaping-machine* is an outcome of the slotting-machine and planing-machine, and may be considered, if not a final triumph of ingenuity, yet as filling the want long left unsatisfied by the other machine-tools. Although used largely for simple slotting-work, such as small key-ways, the chief utility and labour-saving of the shaping-machine are shown by its operating in positions inaccessible to the lathe and ordinary planing-machine. Long after slide and face lathes had been brought to a high state of efficiency, much important work had to be left to expensive hand-labour; but there are now few parts of a steam-engine which cannot be operated on by machinery. Such awkward shapes as a cross-head, a curved link, or the open-jawed end of a rod can be pared and shaped over the entire surface by the machine-tool. Where a curved article has to be cut, the article can—if the radius be within the compass of the machine—be fixed on a central table, which is made to revolve automatically, so as to press forward the article the thickness of one cut at each stroke, against the tool held in a moving arm. In this way incomplete circles to which the lathe cannot be applied are cut, and sometimes the machines are made with two tables and two moving arms. Circular work has been facilitated, both on slotting and shaping machines, by adding a dividing apparatus to the table, so that the teeth of wheels can be accurately cut from the solid, as is done in a wheel-cutting lathe. Shaping-machines are generally made with a horizontal movement, the name of slotting-machine being retained for those with vertical movement. Although, for special purposes, large shaping-machines are made, they are generally classed among the smaller tools of an engineering factory, and a range of price from £50 to £200, will embrace nine-tenths of all that are made. For heavy cuts, however, the slotting-machine is preferable to the shaping-machine, as in the latter the cutting tool presses the work away from the bed. Information as to the nature of the trade, and the kind and size of the pieces to be operated on, is necessary to a proper choice of planing, slotting, or shaping machines. These three kinds of machines resemble each other in that the length of traverse can be varied, and that the return stroke is quicker than the forward or cutting stroke.

Shaping-machines.

How employed.

Will cut awkward shapes.

Or incomplete circles.

Shaping of wheel teeth.

Usual prices.

Large machines.

Milling-machines.

Milling-machines, in which metals are operated upon by serrated rotary cutters, work more effectually and cheaply in certain cases than shaping or slotting machines. Milling-machines are used for cutting spiral or straight grooves or notches, and when these are of moderate size, a revolving tool will, as it advances, cut away the entire width. The kind of work to which these machines are applied may be exemplified by the cutting of slots in hinges or the teeth of wheels or the key-ways in shafts; and in the manufacture of small-arms, clocks, and watches, milling-machines are indispensable. But although most usual for small operations of this kind, special milling-tools have been made for cutting out the slots of locomotive crank-shafts, and it is applied with success as a substitute for the planing-machine in cutting level surfaces of moderate area; but the use of milling-machines for cutting large surfaces is as yet (1880) of doubtful advantage. Milling-machines take the place of small shaping-machines for certain operations, as it is found they do the work more quickly. In this case, the spindle carrying the serrated cutter is linked to a parallel spindle having a blunt or feeler tool working against a pattern of the article to be made, and after the manner of a copying-tool, the cutter follows automatically the form of the pattern, and bites away the metal quicker than by the repeated cuts of the tool of an ordinary shaping-machine. Revolving discs with loose adjustable cutters can be used in the milling-machine for certain operations where there is much to be done, with greater advantage than the serrated cutter, and with less cost of maintenance. Milling-machines cost from £100 to £200, according to size and to the number or variety of accessories.

How employed. Small operations. Sometimes also large surfaces. Used instead of shaping-machines. Copying-tools. Revolving cutters.

Similarity ensured.

One very great advantage afforded by milling-machines is the similarity of the work produced, as the width of cut does not depend on the action of the workman. The making, hardening, and tempering of the serrated cutters together form one of the principal expenses in the working of these machines; but the cutters can be made by the ordinary skilled workmen of an engineering factory, and many of them by means of the milling-machine itself.

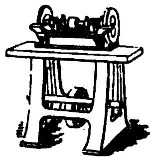
The making of serrated cutters.

Emery-wheel grinding-tools.

Emery-wheel grinding-tools are used with great advantage instead of cutting tools in many operations where a smooth, but not an absolutely true, surface is desired. Thus emery-wheels are used for fetling or trimming small castings, dressing forgings, cleaning wheel teeth, and for sharpening saws. For grinding and sharpening

How employed.

various kinds of knives and cutting-tools, the emery-wheel may in most cases be substituted with advantage for the grindstone. The emery-wheel will also finish the surface of chilled castings, or case-hardened iron-work or tempered steel which are too hard for the file. The machines in form somewhat resemble a lathe, having like it an iron bed or framing (but much shorter than a lathe bed), with a horizontal shaft, upon which is fixed the emery-wheel or disc; but there are numerous varieties in the form of machine; many are made for special purposes, and some are automatic in their action. The emery discs or wheels are made of a peculiar composition, so that they wear slowly and equally, and are of various diameters, from ¼ in. to 36 in., and of thickness to suit the nature of the work or shape to be produced. The discs run at a high velocity (from 5,000 to 7,000 periphery feet per minute being usual speeds), and cut away the metal presented to them very quickly. For most purposes the discs work dry, but for tool-grinding and similar operations they revolve in a trough of water. The emery-wheel is useful in many cases for giving a smooth surface to articles—such as thin pulleys—too light to endure the pressure of a cutting-tool in a lathe; and as preparatory to or as a substitute for the finish of a file, it saves much expense in hand-labour. The simple machines cost from £3 to £30 each; but the more elaborate machines of larger size, with slide-rests and other adjuncts, range in price from £30 to £70 each. The emery-discs weigh from ¼ lb. up to 600 lbs. each, and cost from about 1s. per lb. for large sizes, up to about 2s. per lb. for very small sizes. Although in the majority of cases very great mechanical accuracy is not attempted, emery-machines are occasionally used for very exact work, such as the slide-bars of horizontal engines, and for work of this sort the machine with its appurtenances will weigh from 5 to 10 tons, and be necessarily much more costly than those described above.



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Emery discs.

Size and velocity.

Useful for light work.

Prices.

Used for exact work.

Screwing-machines.

Standard thread.

Screwing and tapping machines are necessary tools in an engineering factory, for although the manufacture of bolts and nuts is a special branch of trade, and engineers often purchase them ready-made, there are many cases when the screwing must be done in the factory. In England, the Whitworth standard thread is universally adopted, but in America the thread, while mainly following the English pattern in regard to the proportion of pitch or coarseness to the diameter differs enough in shape to prevent interchangeability with English screws.

There have been numerous improvements in the methods of cutting screw-threads, so that one workman can in a given time produce more and better screws. Formerly the thread could be formed only by a succession of cuts; now it is formed at one cut.

Separate machines for large and small sizes.

Machines are usually made both to screw bolts and tap nuts, but where large quantities are made, as in a nut and bolt factory, separate machines are employed. Although in the same machine both large and small sizes can be screwed, and such a machine may be convenient for a small factory, it is better generally to narrow the range of sizes and to have more than one machine. Thus one machine, costing with all accessories £60 to £70, may be used for all diameters between ¼ in. and 1 in., while a stronger machine, costing about £100, might include all diameters between ¾ in. and 2 in. Diameters larger than 2 in. have generally to be cut in a lathe, but by improved machines, screws up to 6 in. diameter, with either vee or square threads, are cut at once very exactly. These machines are, however, expensive, and cost about £100 per inch of diameter, and such an expense is only justified where numerous screws of large size have to be made, the saving over lathe-work in such cases soon repaying the greater outlay.

Prices.

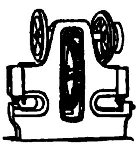
Screwing of large sizes in lathes.

Price of large screwing-machines.

Punching-machines.

See also page 330.

Punching-machines for making holes in cold wrought-iron are among the most useful and necessary machine-tools, and some trades may be said to be entirely dependent on them. For punching the softer metals, such as copper and zinc or thin sheet-iron, hand-presses are sufficient, and are used in large numbers. In these the descending punch is operated by a screw, which is turned by a handle loaded at its ends, or by a wheel with a heavy periphery to act as a fly-wheel, which by its latent or stored energy will force the punch through the metal. In the larger machines used by engineers, the punch is generally operated by a lever and cam, or by an eccentric (a steady motion being ensured by a fly-wheel), these being convenient methods for the short stroke required.



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Capacity, how stated.

The capacity of a punching-machine is expressed by the diameter of hole and the thickness of the plate which can be punched by it; and these two circumstances have to be considered together, for it is difficult to punch small holes through thick plates, the diameter of hole practicable in machines of the ordinary kind being approximately the thickness of the iron. But while the force necessary to the operation may be thus determined, the value of the machine depends also on

the *depth of gap*, or that distance outward from the framing which the punch projects. But while with a deep gap, holes may be punched a considerable distance from the edge of a plate, the strains upon the framing of the machine, always severe during the operation of punching, are intensified according to the leverage of the overhanging arm; and therefore the necessary strength, weight and cost of the machine increase in a growing ratio as the gap is widened. **Depth of gap.**

Punching-machines are generally provided with a shearing apparatus, because the design of the machine and the order of working facilitate the double operation, and because also the trades which require the one process almost invariably require the other also. Small punching-machines limited to holes ½-in. diameter through ½-in. iron plates, or holes ⅝-in. in diameter through ⅜-in. plates, and with a shearing apparatus for ½-in. plates, weigh about 20 cwt., and cost from £35 to £50; while a powerful machine, such as is used in a bridge-building factory, capable of punching 1-in. holes through 1-in. plate, at a distance of 20 in. from the edge, and of shearing 1-in. plates, would cost from £200 to £250, and weigh about 8 tons. Larger machines for punching and shearing 1¼ in. iron, 30 in. from the edge, cost £400. It is customary in the best punching and shearing machines to provide also a special or third apparatus for cropping L bars, this adding about 15 per cent. to the cost of the machine. Special machines for shearing and punching L irons only, are made for ship-builders. Steam-engines are often attached to and form part of large punching-machines, this being in many cases more convenient than the alternative plan of transmitting the power by pulleys or gearing. **Shearing press.** **Cost of small machines.** **Cost of large machines.** **Shearing of angle iron.** *See page 73.*

Various improvements have been made in punching-machines. The shape and dimensions of parts are better adapted than formerly for withstanding the strains and shocks of working, and allow therefore the most economical application of material to the framing of the machine. The methods of transmitting the power to the punch or shears have been improved; and controlling apparatus of a simple kind has been introduced by which the workman, while adjusting the plate or bar to be punched, can instantaneously render effective or inoperative the power of the descending punch; and for particular trades this controlling mechanism is applied to the shearing-blade also. Some punching-machines are provided with self-feeding apparatus, by which the holes are made at regular intervals automatically. **Improvements.** **Controlling apparatus.** **Automatic feed.**

The operation of punching requires considerable care, but good workmanship depends also on the condition of the machine. It is important that the machine be powerful enough to overcome without difficulty the resistance of the iron, secondly, that the die be accurately and firmly fixed so as to receive the punch squarely and without any yielding, and thirdly that the sliding parts should fit closely, for otherwise the hole which is being punched will be distorted and the iron damaged. Moreover, unless there be very great accuracy in the fitting of the punch and die, the latter must be made larger in proportion to the punch than is compatible with good work, and the punch will be apt to diverge laterally from the vertical line and damage the iron. The tighter the fit of the punch into the die the better will be the work done, but the greater will be the strain upon the material, so that not only good tools but iron or steel of good quality is needed to ensure good work. It is mainly owing to the want of knowledge or care in these respects, and the consequent bad results, that some engineers forbid punched holes altogether, and require drilled holes. The reasons adduced in favour of drilling are that greater accuracy is obtained, and that the iron is not damaged as by punching. But unless the drill passes through a template, or at one time through all the thicknesses of iron which are to be riveted together, the coincidence of the holes in the various pieces depends on the accuracy with which they have been marked and the skill of the driller; there being in these respects as much risk of inaccuracy with the drill as with the punch.

Machines must be well fitted.

Adjustment of punch and die.

Iron damaged by punching.

Punching v. drilling.

See STEEL, *page 152.*

Accuracy.

To ensure accuracy in the position of the holes, it has become usual to mark them with a centre-punch, instead of in the more usual manner with colour only, and the punch of the machine is armed with a projecting point or nipple which fits into the centre spot or mark. But marking is altogether avoided sometimes by the use of the automatic feeding apparatus, which so regulates the movement of the pieces to be operated on that the holes are made at regular and prescribed intervals. This method is adopted, for instance, in machines of a peculiar kind, more often used in America than in England, in which numerous punches work simultaneously; the machine somewhat resembling in appearance a planing-machine or multiple drill, the punches being arranged on a cross bridge over a travelling table.

Marking of holes.

Nipple-punching.

Automatic machines.

Good iron is not damaged by the punch if the machine be sufficiently powerful, and if the punch and die be kept in good order as

just described; and a punched hole so produced has, in the opinion of many engineers, some advantages over a drilled hole. Some advantage is claimed for a punch with a spiral face, in which the pressure is exerted at first only on one side of the tool, and is gradually felt over the whole surface as the tool descends, but this method is less advantageous for thick iron.

Spiral punches.

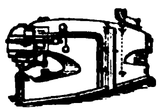
Steel is much more liable to be damaged by punching than iron, though the risk is greatly reduced in the case of mild steel and by the use of a good punching-machine. The annealing of steel after it has been punched goes far to restore it to its original condition. Hard, brittle iron is liable to be damaged by punching, especially with a defective machine, while drilling often allows the use of such iron to pass undetected. There is, however, much to be said on both sides of this question; but as drilling even with multiple drills is a slower process than punching, the rate of production, if drilling be required, is much diminished. There is the great saving in punching that one superior workman aided by unskilled assistants can do as much work as numerous drilling-machines, each of which requires a skilled workman to manage it.

Steel damaged by punching.

Restored by annealing.

See pages 152 and 242.

Hydraulic-power is applied to punching and shearing-machines, the concentration of force rendering possible the direct action of a ram upon the punch without the necessity for cams, eccentric, fly-wheel, or rotary motion. There is the disadvantage in a machine moved in the ordinary way by wheels, that if through inadvertence work be presented to the punch or shear-blade which is beyond its power, some part must break because the impetus of the fly-wheel cannot at once be arrested; this accident often occurring, for instance, in the heavy shearing-machines used by shipbuilders and ironmakers. But this risk of breakage is absent in a hydraulic machine which simply stops if the work is beyond its power. Hydraulic tools find their best place in a workshop where hydraulic power is established for general purposes, because the pumps and accumulator can be provided on a large scale; but as the pumps may be easily worked by the ordinary shafting, which would give power to the pulleys of an ordinary machine, and as a small accumulator is not expensive, one or two hydraulic machines can be established without inordinate expense. For portable punching-machines, hydraulic power compares still more favourably, and indeed renders possible operations which are quite unattainable by other means. The small screw-punch, or "bear," was formerly the only tool available for this purpose, the



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Hydraulic punching-machines.

Advantages.

Pumps and accumulator.

See page 82.

Repetition punching.

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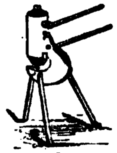
Duplex levers.



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Hydraulic bear.

power being laboriously applied by a long handle or lever; but even the ingenious duplex adaptation of compound levers for this purpose, by which the long handles are rendered unnecessary, is not so efficient as the hydraulic machine. Portable punches as above described are made either on tripod stands, for work that can be brought to them, or without stands, so that they can be carried to girders or other structures and applied in place.

Prices of portable machines.

The simple screw punching-bears cost from £3 to £5 each, and weigh from 25 to 90 lbs., and the duplex machines, which are much more easily worked, cost from £8 to £14, or, if fixed on a stand for punching larger holes, £30. Portable machines of this kind are most effectual for small holes, and they are applied with difficulty for heavier work than ¾-in. holes through ½-in. iron. But for holes in narrow bars such as rails, where the die can be held at both sides, 1 in. through ¾-in. iron or ½-in. steel can be punched by portable screw-machines. Hydraulic punching-bears cost from £10 to £30, and weigh from 70 to 400 lbs. The weight and cost of all portable punching-machines increase in a rapid ratio if a wide gap is required as previously described.

See page 327.

Small holes through thick iron.

Small holes may be punched through thick iron by special machines contrived so as to apply the theory of the "flow of solids." It is in this way that thick nuts with small holes are punched cold, as a persistent pressure of the punch in a peculiar way forces the pellet before it.

Choice of machine, how determined.

The particulars which determine the form, size, and cost of a punching-machine, are the nature of the trade, the maximum diameter of hole to be punched, the thickness of the iron, and the depth of the gap.

Plate-bending machines.

Plate-bending machines, for bending the plates of boilers or ships, are made with three rollers, and the plate being passed below the top roller the desired curve is given by lowering it between the two under rollers, so that the centre of the plate being pressed downwards in passing through, the ends curve up. The machine should be so contrived that the plate after being bent can be removed endways, this being necessary when a plate has been bent to a complete circle.

Plates bent to complete circle.

Plates have to be so bent for the flue tubes of boilers, and sometimes also for the shell of the boiler itself, in cases where it is sought, by using one large plate, to avoid a seam at the bottom of the boiler. It has therefore become usual to make

bending-machines with the upper part of one standard loose, so that it can swing back and allow the plate to be drawn endways from the rollers. While, however, this plan is effective for plates of moderate size, and not exceeding 8 cwt., larger plates, which are used in certain trades, are too unwieldy to be so moved, and to meet these cases, machines with vertical rollers are made, in which plates up to 40 cwt. can be treated.

Vertical machines for large plates.

Ordinary plate-bending machines range in length from 6 ft. to 10 ft., cost from £150 to £250, and weigh from 5 to 10 tons, the weight and cost of the machine being determined as much by the thickness of the plates to be bent as by their size. The rollers are sometimes prolonged beyond the bearings for bending L and T iron, and special machines are also made for bending [and T iron, by passing them while red-hot through three rollers, arranged on the same principle as the plate-bending machines.

Usual sizes and prices.

Riveting-machines are made either for steam or hydraulic power, and, in both, the pressure is applied directly without the interposition of wheels or gearing. In a steam machine, a horizontal cylinder of large diameter is employed, so as to concentrate a sufficient power on the piston-rod forming the rivet-closer. Riveting-machines have to stand a considerable height from the ground to allow structures of varying shape and size to be presented to the riveting tool. The weight and strength of the framing, and therefore the cost, depend more upon the depth of gap than upon the diameter of the cylinder. The prices of steam riveting-machines as used by boiler-makers and bridge-builders range from £250 for a machine with 3-ft. gap, £300 for 4-ft. gap, to £450 for 6-ft. gap; the weight ranging from 8 to 15 tons. The above prices are exclusive of the overhead crane.

Riveting-machines.

Weight and cost.

The superiority of machine over hand riveting lies in the different effects which result from the different kind of blows. A small weight falling with a considerable velocity a great number of times may produce the same aggregate result as a heavy weight falling once with a less velocity, but the effect worked by the former is chiefly in the particles nearest to the tool (the hammer, the rivet-point, and the surface of the plate), while with the latter the effect is transmitted to the more distant or interior particles. A rivet should be heated throughout its entire length, and when inserted should be as hot—and for hand-riveting, or in the case of long rivets, hotter—at the

Machine-riveting *v.* hand-riveting.

See STEAM-HAMMERS *and* PILE-DRIVERS.

The heating of rivets.

head than at the point. The blows of the hammer are not felt so severely at the hilt as at the point, and as at both it is necessary to swell out or "upset" the rivet to fill the hole entirely, extra heat and ductility at the hilt allow the blows of the hammer to have due effect.

Hand-hammering of rivets.

The effect of hand-hammering on a rivet depends on the care and skill of the workmen. If they strike the rivet flat several times, they will "upset" the iron and fill the rivet-hole, but they do not always do this effectually, but begin to form the head prematurely by striking the rivet at an angle, trusting to the cup, or snap-tool, to upset the iron in the hole, which it does not do effectually. A riveting-machine avoids this defect, and moreover has the advantage of pressing the plates, through which the rivet passes, together. Hammering, if continued too long after the rivet begins to get black, causes the iron to crystallize, and rivet-heads so formed are brittle and often fall off. Much depends, however, on the quality of the iron in the rivet, and where very ductile charcoal-iron is used, rivets of moderate size may be hammered quite cold.

Superiority of machine-work.

Quality of rivet iron.

Hydraulic riveting.

Hydraulic-power finds a useful application in riveting-machines, and in the opinion of many engineers offers such advantages over steam-power as to induce them to prescribe hydraulic riveting for all work over which they have control. The operation may be described as a blow and squeeze combined, and to obtain the necessary velocity the power must be brought through the medium of an accumulator, a direct supply from the pumps to the machine not being quick enough. A steam riveting-machine of average size has a piston of 36 in. diameter which, with steam of 50-lbs. pressure per square inch, affords a total force on the rivet-closer of 22¾ tons, while with water of an initial pressure of 1,500 lbs. per square inch, a cylinder 6¼ in. diameter affords the same force. In a steam-machine, there are generally fluctuations in the pressure, and a diminution of 5 lbs. per inch will reduce the force by 2¼ tons; and often when the machine is quickly worked, the diminution is still greater, and there is a corresponding variety in the quality of work done. But in a hydraulic machine supplied with power from an accumulator there is an absolute uniformity in the force applied, although the power can be increased or reduced at will, by simply adding to, or reducing the dead load on the accumulator. Hydraulic machines are particularly useful for rivets of large diameter or where long rivets pass through numerous plates, as the great force which may be applied, closes and holds the plates together in a manner otherwise unattainable. In regard to

Steam *v.* hydraulic pressure.

Fluctuations in steam-pressure.

Avoided in hydraulic machine.

See ACCUMULATOR, *page* 82.

cost, the hydraulic riveter, if considered separately from the arrangements for supplying power, is generally cheaper than a steam-machine of equal power, although the cost of pumps and accumulator (if established for this one machine only), makes the total outlay greater if only one machine be worked; but as one accumulator and one set of pumps will suffice for two or more machines (one of which may be a portable machine), no greater expense is needed in such a case than for a steam-machine. Where there is a complete system of hydraulic machinery, a special steam-engine for pumping is provided; but for one or few machines, the pumps can be worked by belting from the general shafting of the factory, and the expenditure for power so abstracted is less than that taken from a boiler for a steam-machine, as for the latter there is generally much waste of power. Where there is no line of shafting conveniently available for working the hydraulic pumps, the waste heat from the rivet furnace usually suffices for the boiler of a small engine, although the same heat would be insufficient for a steam-machine. There is the great advantage in a hydraulic machine that pressure-water may be brought a considerable distance from the source of power without appreciable loss. The foundations of a hydraulic riveter generally cost less than those for a steam-machine. Hydraulic machines weigh from 5 to 10 tons, and cost from £150 to £500 exclusive of pumps and accumulator. The machines are generally made to exert a force of from 25 to 50 tons on the riveting die, and the gap of the machine can be made of any depth from 4 ft. up to 12 ft.

Comparative cost.

One accumulator serves numerous machines.

Pumps worked by belting.

See page 106.

Waste heat utilised.

See page 82.

Weight and cost of hydraulic machines.

The *Portable hydraulic riveter*, according to Tweddell's system, exemplifies the peculiar advantages of water-transmitted power more than any other operation to which it has been applied. By means of a machine measuring about 1 ft. by 2 ft., and weighing only from 300 to 400 lbs., a pressure of 30 tons can be applied to the closing of a rivet in its place as part of a large structure—girder, bridge, ship, or boiler—which would be quite inaccessible to a fixed machine, and without such a method, only to be performed by hand-labour. This concentration of power in a small compass is rendered possible by the high pressure which can quickly and easily be obtained from hydraulic pumps through an accumulator, and to the simple and effective jointing or articulation of the small tubes through which the water is conveyed, and which allow the machine to be moved from place to place almost as readily as a portable gas-lamp supplied by an elastic tube. It is in the movability from the source of power, and in the

Portable riveter.

Tweddell's system.

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quick stroke which the accumulator affords, that the portable riveter differs from the hydraulic lifting-jack, for in both the force is obtained in a small portable machine by the use of high-pressure water on a piston or ram of small diameter. A hydraulic riveter as just described costs only about £100 if used where hydraulic pumps and accumulator are already established, but an additional cost of from £170 to £200 must be incurred if these have to be made. This is still exclusive of the engine-power for the hydraulic pumps, which can however be generally worked from an existing line of shafting, with an expenditure for the force abstracted much less than that which would be required in wages for hand-riveting. The cost of overhead cranes or travellers has generally to be incurred, the kind and cost depending on the nature of the work to be operated on. Machines of this kind have been found effective not only in boiler-making, in the bridge factory or ship-building yard, but for riveting *in situ* during the erection of large bridges.

Cost.

Cost of pumps.

Overhead crane needed.

Compressed air is sometimes employed as the medium of power for portable riveting-machines, the apparatus, in regard to portability and shape, much resembling the hydraulic riveter. As however it is not convenient to use air of great pressure, the force is applied in a totally different manner than in a hydraulic machine. There are two systems, one, in which a rapid succession of blows, each of only moderate force, is given as in a rock-drill, with a result like that in hand-riveting, and the second where one blow only is given, but with a power multiplied by a lever.

Power by compressed air.

See pages 86 and 91.

See page 94.

See ROCK-DRILLS, *Chap. XXVI.*

Referring to the various operations described in the preceding pages, *the Choice of machine-tools* is greatly assisted by a plan of the workshop showing the position the machines are to occupy and the space available for them; an elevation and cross-section showing the driving shafts, their distance from the wall and roof (thus indicating the length of belts and clearance-space for pulleys); the thickness of the wall or roof-beams available for supporting overhead gear; and information as to the diameter and speed of the shafting which is to drive the machine. In England, machine-tools are generally fixed upon stone beds, but timber is sometimes employed. Stone is preferable to timber, but as concrete will serve equally as well, it is easier and cheaper to export Portland cement to countries where indigenous stone is wanting, if suitable gravel, ballast, or other material for making the concrete be obtainable in the locality.

Choice of tools.

Workshop plan.

Supports for shafting.

See page 104.

Foundations.

Concrete.

See CEMENT, *Chap. XXVII.*

The importance of fixing a machine exactly level on a solid foundation cannot be overstated, for not only is the correctness of its work imperilled by an uneven or yielding bed, but the labour of fixing the article in the machine is increased, for it is always convenient to adjust the article by the spirit-level on the assumption that the operating-tool will work exactly parallel or at the desired angles to the horizontal line. **Machine bed must be solid.**

Great care is necessary to ensure a solid bearing at all points, for if the supports are not in a true plane, the machine, especially if it covers a large area, may, in settling down to the place provided for it, become distorted or strained. Indeed some engineers consider it so difficult to adjust exactly four bearing places, that they prefer to make only three of the supports rigid, which can be arranged without difficulty, and to make the fourth jointed or otherwise adjustable to allow of exact setting. **Adjustable bearings.**

A full knowledge of the purpose for which the machine-tool is intended greatly assists a proper choice, for there are many alternative arrangements of detail from which can then be selected the one suited for the case in view. Moreover, if a constant repetition of similar work is intended, special self-acting or automatic arrangements can be provided to increase the service and to cheapen the cost of working. On the other hand, special machines which may be useful in large factories are out of place when the work is of miscellaneous kind or is limited in amount. Summarising the suggestions conveyed in the preceding pages for particular tools, it may be stated generally in regard to all, that, to allow of a proper selection of the machine needed, the following information should be furnished by the purchaser :— **Choice of machine, how determined.** *See pages 48, 265, and 311.* **Particulars enumerated.**

1. A description of the trade for which the tool is needed. **Purpose.**

2. The size and weight of the pieces or articles to be operated on. This may either be given by approximate dimensions and weights, or may be sufficiently indicated by a description of the commodities to be manufactured. Thus, in the case of locomotive, marine, or stationary engines, their size or horse-power will convey a good idea of the capacity of the machine-tools necessary. So if ship-building be the trade, the size and kind of vessel built will tell approximately the strength and size of the various tools. *See page 67.* **Size of pieces.**

In purchasing machine-tools, it may be sufficient to furnish the foregoing particulars to the manufacturer, on whom will then rest the responsibility of supplying what is suitable. If competitive offers **The purchase of tools.** *See page 13.*

See page 5.

have to be considered, a specification and drawing from each maker will be required in order to allow a comparison of values. To facilitate such comparison and to narrow the differences of various designs, certain main features may be prescribed by the purchaser. In the first place, the strength or quality of the materials may be described. Cast-iron may be specified by the breaking strain and deflection of a standard test-bar, but a proper selection of the iron depends on the kind of machine. Thus in the bed of a lathe or planing-machine, rigidity is of the first consequence to allow of heavy cuts at maximum speed, as any yielding or springiness would be fatal to the accuracy of the work done. A saving in weight by having tough metal would therefore be inexpedient, while on the other hand, toughness and elasticity are essential qualities in toothed wheels or in the framing of a punching-machine. The tensile strength of the wrought-iron, the kind or brand of steel, and the alloy of brass, are also points of importance. Conditions of quality such as these may be safely left to manufacturers of repute, but certain points must be specified to allow a proper comparison of competitive prices. Certain leading dimensions of length, width and height may be stated, as well as the scope of the machine in regard to the size of the article to be treated. But such particulars are not conclusive unless the speed and capacity be also stated, as the framework, while large enough for the desired purpose, may not be so strong as another for cutting or piercing at a profitable speed the metals dealt with. The specification, whether of buyer or seller, should enumerate the accessories or duplicate parts that are to be supplied. It is usual for the machine-tool maker to include in the price the brackets, pulleys, and other driving apparatus for transmitting and regulating the power from the main shaft of the factory, but as such a condition may admit of different interpretations, the various appurtenances should in each case be described. But to enable the manufacturer to calculate the size, shape and cost of these parts, the purchaser must first state the speed of the shafting and diameter of the pulleys from which it is proposed to give power to the machines, and also the nature of the supports—roof beams, walls or columns—to which the shafting brackets are to be fixed. So also the driving-belts, cutting-tools, tool-holders, spanners, holding-down bolts, and other minor parts should be enumerated.

Quality of material specified.

See page 133.

See page 137.

Accessories included in price.

See page 180.

See page 104.

Packing for shipment.

See page 35.

Machine-tools generally pack closely for shipment, the weight usually exceeding the measurement tonnage. Large or long pieces require special protection against damage, and all small parts have to

be packed in close cases. The cost of packing for shipment ranges generally from 3 to 5 per cent. on the purchase prices.

Management of machine-tools.

See page 64.

The proper *Management* of machine-tools is one of the most important conditions in the profitable carrying on of an engineering factory. In regard to the machines which have been enumerated in the preceding pages, it is obviously important to utilise them to the utmost by having the most perfect cutting-tools, and by keeping them fully employed; but too often, even when care and money have been expended without stint on the machines, the results are inadequate for want of attention to these conditions. Assuming that the machine has been well chosen in regard to the work to be performed, the amount of service depends mainly on the following points :—

Readiness of attachment.

(*a*) The *readiness* with which the article can be attached to the machine and adjusted, more time being often expended in this than in the actual working of the tool. Much invention has been directed to these operations, and the less variety there is in the size and shape of articles, and in the kind of service required, the more scope will there be for improvements and for the application of "special" tools.

Shape of cutting-tools.

Steel of suitable shape.

See page 155.

(*b*) The *shape* of the cutting-tool and the manner in which it is held. Skilled workmen acquire great aptitude in the shaping of tools to the proper form, and in their ready application to the purpose in view, but they are greatly assisted by having steel of appropriate shape from which the tools can be fashioned, well-contrived grindstones or emery-wheel grinders, and tool-holders which allow quick adjustment.

Quality of steel.

See page 156.

Durability.

(*c*) The operation of a cutting-tool and its endurance obviously depend much on *the quality of the steel* and on its suitability to the metal it is to cut, though this consideration does not always receive the attention it deserves. The better the steel, the longer it will work before needing to be re-shaped or re-ground; and by a careful choice of the kind of steel, the maximum speed of the cutting-tool can be obtained, there being wide limits within which economy in this respect may be promoted.

Cutting speed.

Profitable results.

(*d*) The *cutting-speed* of machine-tools, and the depth and width of cut, should be carefully studied by those who have the management of workshops. In many cases, even where attention is paid to other points, these are left to the discretion or whim of the individual workman, while it should be obvious that on them the profit or loss which will result from a given outlay in machinery, wages, and current expenses almost entirely depends. The amount of work

which machines of similar kind and capacity will produce, varies even in first-class factories as much as 50 per cent. The necessity and the advantage, both to employer and workman, of payment by results are ever becoming more evident, but the scale of payment for piece-work can only be equitably arranged on some standard basis in these respects. The area of surface finished in a given time, or the number of holes punched or drilled, should be tabulated for each of the metals dealt with, and some standard set up. Even then the best results can only be obtained by a wise expenditure, in the first instance, on true and powerful machines that can be worked at a maximum speed. But with respect to the width, depth, and speed of cutting, not only the power of the machine has to be regarded, but also the strength of the article operated on to resist the pressure of the tool.

Piece-work.

Based on speed of tools.

Other points to be considered.

See EMERY-GRINDING, *page 325.*

(*e*) Even with the best machines and cutting-tools, the cost of working depends greatly on the *organization* of the workshop and the order of procedure. In many cases, one skilled workman, assisted perhaps by a boy or labourer, can manage two or more machines; and although such an arrangement is often opposed by the fallacious reasoning of trades-unions, it is obvious that the workman who can so utilise the machinery, enhances the value of his services. Wherever possible, relays of tools should be in readiness to replace those which are worn or broken, and in many factories, the workmen who control the machines are not allowed either to shape or grind their own tools, as not only their own time but the valuable time of the machine is lost while they are absent from it. In well-managed factories, store-rooms are provided for loose tools, which are kept in good order and issued to the workmen in a systematized manner.

Organization.

See page 64.

One workman to two or three machines.

Grinding of tools.

Systematized tool stores.

(*f*) *A clean, well-ordered workshop* has much to do with the good condition of machine-tools. A floor of wood blocks, or asphalte, or other substance which gives out little dust, is an advantage. The wearing parts of the machines should be preserved as much as possible from dirt and grit, and oil of good quality only used. Under favourable conditions in these respects, the workmen will be found to take care and pride in keeping their machines in good order; and even some degree of smartness—such as the polishing of bright surfaces—may be encouraged, because such attention generally brings with it care to the more essential parts of the machine.

Clean workshops.

Flooring.

Machines kept in good order.

[*See also* THE ESTABLISHMENT OF FACTORIES: THE TRANSMISSION OF POWER: *and* SMITHY TOOLS.]

CHAPTER XXIV.

SMITHY TOOLS AND STEAM-HAMMERS.

A WELL-ARRANGED and well-kept smithy is generally evidence of good management in an engineering factory; but very often, even where skill and money have been expended on the other departments, the arrangements of the smithy are rude and defective. Smiths' hearths are generally arranged along the wall, and the anvils, steam-hammers, and other machines in the centre of the smithy. This plan economises space; one line of blast-pipe will serve all the fires; and cranes, if needed as adjuncts to the hearths, can be conveniently attached to the wall. The hearths may be placed either singly or in pairs, or sometimes even in groups of three or four; these arrangements and the distance between the hearths depending mainly on the dimensions of the forgings to be made. The smoke and fumes from the hearths may be conducted either by bend-pipes from the hoods to chimneys constructed in the wall, or vertically by light iron chimneys through the roof. Where hearths are arranged in pairs, they are sometimes covered by one hood; but this plan, though effective, requires a hood of large size, and is inconvenient to make and carry. It is sometimes found convenient to conduct the smoke from numerous hearths to one chimney, through a horizontal tube of large diameter, with which the hoods of all the hearths are connected. A smithy should be lofty and well ventilated; the floor should be made of iron borings, wood-blocks, or other compact substance kept clean and watered, and there should be an abundant supply of water conveniently placed; the comfort and efficiency of the workmen being much promoted by such arrangements.

Well-arranged smithy.

Hearths placed singly or grouped.

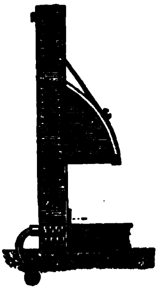
Smoke-pipes and hoods.

Ventilation.

Smiths' hearths may be broadly classed as of brick and iron.

Hearths made of brickwork.

Brick hearths are preferred by some engineers: they are easily built, and in a foreign country, where good bricks are made, require the minimum of imported material. A cast-iron back-plate, tuyere, and water-cistern cost from £4 to £8, according to the size of the hearth; and the rest of the structure may be made of brick. To ensure a proper upward draught, a hood is generally necessary to conduct the smoke and gas fumes to the chimney; and the hood, if of brick, is conveniently supported on an angle-iron frame, held back to the wall or chimney by tie-rods. Brickwork is preferred sometimes because less heat radiates from it into the smithy than from iron, but the same advantage is obtained in an iron hearth by lining it with fire-brick. In some cases the hood is made of brickwork for its supposed coolness, while the base and fire-pan of the hearth are made of iron. The ironwork for such a hearth costs little less than a hearth entirely of iron. It is sometimes sought to avoid hoods altogether, and hearths so arranged are found to work well in some factories. But this plan is only possible by a special system of ventilation, a vertical draught sufficient to carry the smoke to outlets in the roof being ensured by doors or other air inlets in the side walls.



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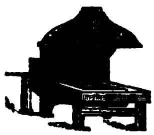

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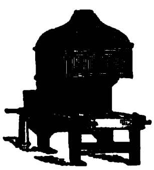
Iron hearths.

Iron hearths are generally preferred to brick hearths in modern engineering factories, as they are self-contained, occupy less room, can be purchased ready-made, and are cleaner in use. They are generally made of cast-iron, except where the risks of breakage in long or difficult land-carriage render wrought-iron safer. Cast-iron hearths, as suitable for ordinary engineering smithies, weigh from 10 to 22 cwt., and cost from £10 to £25. Hearths of particular shape and size are made for many of the special purposes in an engineering factory. For large forgings, circular hearths standing clear of the wall, and with a converging blast from three tuyeres, are often employed. Such a hearth, for instance, is used for heating railway wheel-centres. Suitable hearths or furnaces are generally provided as accessory to a steam-hammer, and in such cases not only is the hearth made of special size and shape, but hearth, crane, and hammer are designed and arranged as one apparatus, so as to allow the best and cheapest sequence of operation. For small forgings, such as for carriage ironwork, small-arms making, and other special repetition-work, small hearths of appropriate shape are contrived; they are often enclosed instead of open in the way usual for ordinary smithing. Sometimes the hood is raised, and its lower part lined with fire-brick

Weight and cost.

Converging blast.



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set in fire-clay. Fire-bricks of ordinary size and kind may be used; such bricks cost about 1d. each, and are exported in considerable quantities, but they are occasionally made of special shape and size to fit the hearths. For out-of-door work, smiths' hearths are sometimes made without a hood; but it is then generally found necessary to provide a screen as a shelter from the wind.

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The fire-plate of a hearth is often made of special size and shape to suit particular work. For certain rough or heavy forgings—such for instance as anchors and chain-cables—a hearth-plate stronger than usual is necessary.

Improvements in hearths.

Various improvements have been effected in smiths' hearths.

In the mode of producing the blast. In the tuyere or nozzle by which the blast is admitted to the fire.

Bellows.

The hand-bellows produces a blast slowly and laboriously, and for large forgings is inadequate. It has long been superseded by rotary fans or blowers wherever power is available for working them, and even where mechanical power is not obtainable, hand-machines are often preferred to bellows.

Fan.

The *Fan* in some respects resembles the centrifugal pump, for it is circular, is armed with radial blades, and revolves inside a case. To raise a blast sufficient for a smith's fire, a high speed is necessary; from 1,200 to 1,500 revolutions per minute being ordinary rates. A fan sufficient for supplying 7 fires with blast costs about £8; while one for 15 fires costs about £16. To these prices must be added the cost of the shafting, pulleys, and belts between the motor and the fan, which are required to multiply the speed.

Blower.

The *Blower*, which was invented long after the fan, is, in the opinion of most engineers who have tried it, a much better machine for producing a blast. It has a rotary motion, but it revolves at about one fifth of the speed; it works in a close-fitting case, and forces the air steadily before it, instead of like a fan merely beating the air. A blower is more costly than a fan, but requires fewer shafts, pulleys, and belts, and less power is necessary to produce a given blast.

Air-blast conducted in pipes.

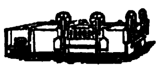
The blast from a fan or blower can be conducted a considerable distance in pipes, which are generally laid about one foot below the ground or floor of the smithy. Sometimes wood or brick conduits, or earthenware pipes, are used; but iron pipes are generally preferred, as they are tighter against leakage, are less liable to fracture, and there is less surface friction.

Air pressure.

The pressure is so slight that sheet-iron pipes are strong enough, though they are less durable than cast-iron

See page 235. against rust; the choice depending upon which is more easily obtained in the locality.

Stand-pipe. By the side of the smith's hearth, a stand-pipe with simple shutter-valve or plug-valve conducts the blast from the underground pipe to the nozzle which enters the hearth. As the blast has to be conducted into the heart of the fire, the nozzle is liable to be burnt away by the intense heat, and to preserve it as much as possible the **Water tuyere.** water-tuyere is generally used. This tuyere is a double pipe of cast-iron passing through a cistern behind the hearth, and the annular space being kept full of water, the effect of the fire on the nozzle is **Disadvantages.** thus greatly counteracted. Water-tuyeres are bulky, necessitate a cistern of water, and are not always used even in fixed hearths, and hardly ever in portable forges. One plan of supplying air without **Vertical tuyeres.** the water-tuyere, is to bring the blast from below by a vertical pipe into the centre of the hearth through a small perforated plug or plate, which fits into the mouth of the pipe. Such a plate is not so much exposed to the intense heat of the fire as a nozzle which projects horizontally, and it can be cheaply replaced when burnt. The fire-pan of a hearth so supplied with air can be made shallower than that of an ordinary water-tuyere hearth; but although many smiths who have used them prefer the vertical blast, the horizontal water-tuyere is (1880) used in the majority of cases. The plan of a central tuyere has been elaborated by making the plug to move upwards, so that it not only serves to regulate the blast, but, when so moved, to clear the fire.



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Closed furnaces. *Closed furnaces* are used for many of the processes in an engineering smithy, for which a smith's or open hearth, which concentrates an intense heat on one lump of iron, or on one portion of a large piece, would be quite unsuitable. When large surfaces have to be brought to an equable heat—as in the case of boiler-plates or wheel-**For heating plates or wheel-tires.** tires—an enclosed furnace without a force blast is used, the necessary draught being provided by a suitable arrangement of the flues and chimney. The article to be heated is not brought into contact with the hot fuel as in a hearth, but the heat, generated in one corner of the furnace on ordinary fire-bars, passes through and around the chamber to be heated. Furnaces of this kind are built of brickwork, with a lining of fire-brick, and are encased in iron and held together by outside tie-rods against the heat-expansion, which would other-**Fire-bricks.** wise crack or break them. The brickwork may with advantage be *See page 341.* entirely of fire-bricks jointed with fire-clay, but often a lining of fire-

bricks is built within ordinary bricks. Roughly-made cast-iron plates may be used as the outer casing. Wrought-iron is sometimes preferred as being less fragile; but if cast-iron plates become broken, as is almost sure to happen eventually, they are still serviceable, if there be sufficient connections and bolts. Old boiler-plates with numerous perforations are also effective for the purpose. The ironwork for furnaces as just described, of the kind used in a locomotive factory or general engineering works for such purposes as tempering steel springs, heating wheel-tires and centres, or for heating scrap-iron for hammering, weighs from 8 to 20 tons, and costs from £80 to £150 according to the size and purpose required. Larger furnaces are needed for heating large masses of iron in those factories where powerful steam-hammers are employed. Small brickwork furnaces, similar in kind, are used instead of forges for heating rivets in a bridge or boiler factory where, as for a riveting-machine, many rivets have to be supplied quickly.

Iron casing to brick furnace.

Weight and cost.

Rivet furnace.

Of the many miscellaneous tools used in a smithy—cranes, anvils, swage-blocks, swages, fullers, and hammers are the most important. Light wrought-iron cranes attached to the wall, or to the side of a furnace for lifting forgings from the fire to the anvil, cost from about £12 for one lifting 5 cwt., to about £20 for one lifting 20 cwt.; while for lifting heavy forgings to and from a steam-hammer, more powerful and expensive cranes are required. Anvils for small forgings weigh from 2 to 3 cwt., and cost about £5, but for an ordinary engineer's smithy the anvils weigh about 4 cwt., and cost about £8. Anvils are frequently fixed upon a block of timber, but sometimes on cast-iron stands weighing 2 to 3 cwt., costing from £1 to £2. Swage-blocks are made of cast-iron, are generally rectangular, are perforated with variously shaped holes, and have grooves on the sides by which the smith is assisted in hammering and twisting the iron he is forging; and the blocks serve also sometimes to hold loose swages or dies. These blocks weigh from 2 to 6 cwt., they may be supported on a wooden block, or on a cast-iron stool like an anvil block, and they cost from £2 to £4.

Smithy tools.

Cranes.

See page 359.

Anvils.

Swage-blocks.

Among the loose tools in a smithy, iron hammers with steel faces cost about 7d. per lb., and steel about 12d. per lb. Swages are made of wrought-iron or steel, and are made convex or concave in a variety of shapes. These, as well as the tongs and cutting-sets, a good smith will often prefer to make for himself; but in establishing a new factory—especially in a foreign country where there are not smiths skilled

Hammers.

Swages.

enough to make such tools—it is usual to purchase them. Iron tools cost about 6d. per lb.; steel tools 12d. per lb.; and those of iron and steel combined, 9d. per lb.

Cost of small tools

Portable forges.

With bellows.

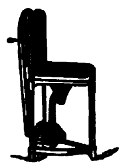
Portable forges are made in various ways, and in all it is endeavoured to obtain the maximum capacity with the smallest weight and size. The majority of small forges have leathern bellows—square or round, according to the shape of the forge—worked by a hand-lever or by a foot-treadle. The bellows is generally made double-acting, so as to emit a blast during both the up and down movement, the current of air to the fire being thus almost continuous. Light sheet-iron forges thus equipped with bellows cost from £5 to £8. They are known as "deck or riveting forges," and are generally used by ship-builders, bridge-makers, boiler-makers and gas-holder makers, for heating rivets, and they can easily be carried from place to place. Such forges, as generally made, are cheap and fragile, and do not last long. As the bellows affords only a small blast, attempts have been made in various ways to apply the fan or blower. As it is essential that a fan shall revolve at a high speed, quickly-running belts, pitch-chains, or toothed wheels are necessary, which, inconvenient at all times, are especially unsuitable and liable to damage in a portable forge. The blower has, however, been successfully applied, and forges so equipped form permanent and efficient tools, suitable not only for heating rivets, but for ordinary smith's work in factories where forgings of moderate size and thickness are made, and where there is no blast from a fixed blower available. These forges are serviceable in the engine-rooms of steam-ships, for workshops on upper floors, and in all places where a large or brick-built hearth is inconvenient. The forges are made either of cast-iron, or of a combination of cast, malleable-cast, and wrought-iron, and the best of them are ingeniously contrived so as to allow, in a small space, forgings of considerable size to be brought to welding heat in a short time. The forges range in price from £8 to £16, and weigh from 1 to 6 cwt., the larger size being capable of producing a welding heat in a bar $2\frac{1}{2}$ in. diameter in five minutes. In remote places, where occasionally forgings beyond the capacity of a portable forge have to be made, a temporary brick hearth can be built, a blower complete on a stand with hand-gear being alone imported. For the military train or artillery service of an army, portable forges are specially contrived to resist fracture, and to fold up into small space for carriage on the pack-saddle or baggage-wagon.

Deck forges.

Fan blast for portable forges.

The blower blast.

See page 341.



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Strong forges of iron.

Steam-Hammers are conspicuous among the numerous inventions, the outcome of the steam-engine, by which the ruder operations of the workman are performed by mechanical force. In the smithy of an engineering factory, before the invention of the steam-hammer, almost the only means of forging iron in pieces larger and heavier than usual was to increase the number of men wielding striking-hammers. From two to six men would be employed, so as, by striking in turn, to give a continuous succession of blows. Strong and skilful as these workmen became, they could at most only wield hammers of about 20 lbs. each, and the blows fell with feeble effect on the masses of iron with which they dealt. Where such were the only means available, the iron had to be heated several times; the outlay for fuel was therefore great; the strikers were idle between the heats; welding of large or heavy pieces was imperfectly performed; and as the size of forgings was limited by the force available, cast-iron or timber had often to be employed in structures or machinery, where forged wrought-iron would have been preferable. **Steam-hammers.** **Compared with manual hammers.** **Limited in effect.**

Various mechanical contrivances for aiding or cheapening the forging of iron were in use long before the introduction of steam-hammers, but such contrivances were unsuitable for miscellaneous smith's work. In the process of iron-making, various kinds of tilt or cam hammers, worked by steam or water power, were devised for compressing and hammering the "blooms" of iron before they were rolled into bars or plates. The power was applied to the lifting or tilting the hammer or tup, the useful work being performed by the falling weight, but the fall seldom exceeded 15 inches, and only about fifty blows at most could be given per minute. Moreover, no adjustment or regulating of the blows was possible, and it was difficult to apply such hammers to any but simple processes of an accustomed kind. For small repetition work, such as the making of bolts, spikes, nails or rivets, small tilt hammers of various sorts were in use a hundred years ago, and are still employed by the numerous craftsmen and home workers in the hardware districts; and in particular trades there are often minor operations in a smithy where tools of this kind may be employed with advantage if steam is not readily obtainable, especially if power-shafting or water-power is available for working the tools. **Tilt hammers.** **For iron blooms.** **Disadvantages.** **Small tilt hammers.** **Still employed.**

The first steam-hammers by Nasmyth were single-acting, that is to say, the steam was employed only to lift the tup; but heavier hammers and quicker blows were at once rendered possible. The special **Nasmyth hammer.**

and novel feature in these was the valve, by which the workman could, by admitting steam below the piston, arrest the falling weight at any desired distance from the anvil, and by interposing what is in effect a cushion of steam, make the blow thus shortened at will also light or elastic.

Single-action hammer.

The single-acting hammer was soon improved by admitting steam above the piston, thus adding immensely to the force of the blow; the power in this respect being indeed only limited by exigencies of transport, which determine the size and weight of the framing, and by the stability which can be given to the anvil and its foundations.

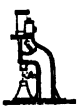
Double-action hammers.

Advantages afforded.

These double-acting hammers at once revolutionised the art of forging, increased the size of blooms, and consequently of bars and plates in the rolling-mill, cheapened most kinds of smith's work, and rendered possible the manufacture of the enormous engine-shafts, rudder-posts, armour-plates, guns and other articles, where large masses of wrought-iron have to be dealt with.

Single-action hammers still used.

Single-acting hammers are quite obsolete in most engineering factories, but they are still preferred in some cases for use as large-size heavy forge-hammers, when rapid striking is not required. They are less liable than double-acting hammers to break down.



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Single-frame hammer.

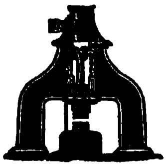
The single-frame hammer is the most convenient for smith's work, as it affords the maximum space within which the forging may be moved. The workman can stand either in front or at the side, as the shape of the forging or the nature of the work requires, the regulating handles being accessible from either position. The greater the distance A, the more space is there for the articles dealt with, and a blow can be struck or a welding effected at a greater distance from the edge of the article; this being occasionally a great advantage. But it is obvious that the overhanging cylinder imposes severe strains on the framework or standard of the machine, which in this respect may be compared to a punching or drilling machine, where any increase in the depth of gap rapidly increases the strains on the frame-work.

Depth of gap.

See page 327.

Hammers of this type suitable for moderate-sized forgings, are rated at from ½ cwt. to 10 cwt.; have cylinders ranging from 4 in. to 12 in. diameter; weigh from 1 to 8 tons (including anvil-blocks); and cost from £50 to £200. They are occasionally made with cylinders as large as 15 in. diameter, and are rated to 20 cwt.; they then weigh up to 17 tons, and cost about £300; but beyond the usual limit of 12 in., the single standard or support, to be of sufficient strength, is cumbrous and inconvenient, and the double support becomes necessary.

Sizes and prices of hammers.



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Double-frame hammers.

It will be seen that this form of machine affords a greatly increased capacity, and, as already stated, the limit of size is determined by such circumstances as the stability of foundations to receive the shock, and the carriage of heavy pieces from the manufactory, rather than by any difficulty in making the hammer itself sufficiently strong. But the cost of such machines increases rapidly with the size, and especially with the width, which, however, may be often advantageously made large at extra expense. Hammers of this kind are seldom made with cylinders of less than 10 in. diameter, with a rating of 7 cwt., a machine of such a size weighing about 6 tons including anvil-block, and costing about £150. In an engineer's factory, a hammer with a 15-in. cylinder, rated at 20 cwt., costing about £300, is seldom exceeded; and if, to save carriage to a foreign country, the anvil-block or base-plate be omitted, the price would be about £200. Occasionally 50-cwt. hammers are used for making large crank-axles, although in many cases where large forgings are only occasionally wanted, it is better, instead of attempting to make them, to purchase them from those who confine themselves to the manufacture of heavy forgings. It is in iron or steel works that the larger steam-hammers are needed. For shingling iron blooms, a process preparatory to that of the rolling-mill, hammers with cylinders of about 19 in. and rated at not less than 50 cwt. are usual; such a hammer costing about £600; while for hammering steel ingots into blooms of a size usual in an English steel-rail factory, a 100 cwt. hammer, with a cylinder not less than 28 in., would be required, costing about £1,200, or £500 less if the anvil-block or base-plate be omitted. From this size upwards, hammers are generally made specially for the purpose in view, the heaviest being those used in the manufacture of armour-plates and big guns. Some of these hammers are rated at 80 tons, and cost, with anvil, boilers, and other appurtenances, £6,000 and upwards. In some iron and steel works hammering is entirely avoided, steel ingots and blooms being reduced by rolling, and iron blooms being passed through revolving squeezers, which effectually rid them of cinder. But some engineers still prefer iron or steel which has been hammered.

Usual sizes.

For an engineer's factory.

Purchase of forgings.

See page 67.

Large hammers for iron and steel works.

For shingling blooms.

Hammers for heavy forgings.

Squeezers instead of hammers.

Steam-hammers are (1880) generally rated according to the weight of the falling tup, including that of the piston and rod, which of course add to the effect; but it is obvious that the mere dead weight of the falling parts gives an entirely inadequate idea of the force of the blow, which depends, not only on the velocity arising

Rating of steam-hammers.

By weight of falling parts.

from the depth of the fall, but, in double-acting hammers, on the steam-pressure on the piston. There is no established standard or measure by which to rate the real force or effect of a steam-hammer. If the impact of a sledge or striking hammer of given weight wielded by a workman could be calculated or measured, it, as affording accustomed results, might form an useful unit by which the power of a steam-hammer could be rated, but as no such standard has been set up, purchasers of steam-hammers have to calculate for themselves the force at their disposal, or to rest content with the assurances of the makers, or to judge by observation of the effect of similar hammers.

A better standard needed.

Approximate rating.

The force of a steam-hammer can, however, be approximately measured in a way which would allow a comparison of different sizes and kinds. If a certain pressure of steam be assumed, then the force on the piston added to the weight of the falling parts and multiplied by the length of the stroke in feet will give the *data* by which the growing velocity and ultimate force in foot-lbs. or foot-tons may be calculated. For instance, if what is known as a 50-cwt. hammer (the falling parts weighing 50 cwt.) have a piston 20 in. diameter, and a stroke of 4 ft., then if steam equal to a pressure of 50 lbs. per square inch be employed and maintained till the end of the stroke, the blow on the anvil would equal about 38 foot-tons; that is, it would, if striking on one end of a lever, raise 38 tons 1 foot high on the other. Of this force only about one-fourth would be due to that weight of falling parts by which hammers are nominally rated. Or, to take a smaller example, a hammer with moving parts weighing 5 cwt., with a piston 9 in. diameter, a stroke of 21 in. and 50 lbs. of steam, would give a force of about 2½ foot-tons on the anvil. These theoretical results have, however, to be qualified in several ways. First, the friction of the moving parts must be deducted, but this is very small, and may almost be disregarded. Then it is hardly possible to so adjust the valves that the steam will exert its full pressure on the piston absolutely at the beginning of the stroke, and the velocity at the end may therefore be slightly less than that calculated. Further, as the iron to be forged interposes between the anvil and the tup, the stroke is reduced, and the velocity and force of blow rendered less than with a full stroke. But even with these deductions, it might be convenient, as a means of comparison, to rate hammers according to the maximum gross force of blow which they can give on the anvil, leaving the user to diminish as he pleases the actual force, either by limiting the stroke, or by cushioning the blow by means of the steam-valve.

By foot-pounds.

See page 160.

Examples.

Theoretical results qualified.

Friction.

By shortening of stroke.

Gross force.

Steam-hammers give four kinds of blows.

Enumerated.

There are four kinds of blows which can be given by a double-acting steam-hammer: 1st, the single-acting blow by which the steam is only admitted for the upward stroke, the work being performed by the falling weight; 2ndly, the above method controlled or cushioned by the admission of steam below the piston as it falls; 3rdly, the pressure-blow with steam above the piston, but cushioned as in the second method; and 4thly, the "dead blow," by which the full pressure of the steam is applied above the piston during the whole stroke, and also after the tup has fallen, so that it not only descends with its greatest force, but remains as a squeezer on the forging. The action of the hammer in these respects is entirely controlled by the valve-lever, and by one man, who soon becomes able to regulate the blows with the greatest nicety to the purpose in view. In the largest machines the workman stands on a small platform affixed to the side of the framing, and in smaller machines on the floor of the smithy. In all but the smaller-sized hammers, there is a driver who works the valve-lever of the machine, under the orders of the hammer-man, who guides and controls the forging. But in the smaller machines and steam-stamps the hammer-man is himself able, by a treadle-lever, to work the valve with his foot. Such a method, which economises the cost of labour, is commonly adopted for light forgings, such as files, cutlery, and bolts. The number of blows per minute ranges from 50 per minute with the largest hammers and the heaviest forgings, to 300 and 400 per minute in hammers and stamps of small size.

Blows, how controlled.

Small hammers worked by one man.

Number of blows per minute.

The weight or power of hammer that is best for any particular operation depends almost entirely on the massiveness of the piece of iron to be treated, for though numerous light blows may express the same aggregate force as a few powerful blows, the result is entirely different. Light blows take effect only on the part immediately presented to them, while a heavy blow is felt by the mass. Thus, if a forging A, be presented to a light hammer, the effect will be as at B, while if struck by a heavy hammer the effect will be as at C. In this respect the difference between hand and machine-riveting or between manual and machine pile-driving afford analogous cases.

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See page 331, also PILE-DRIVERS.

Concussion loosens hammer-framing.

The concussion to which a steam-hammer is subjected, tends in time to loosen the parts, and when once they are out of true line, they will break if further work is attempted. To resist these loosening strains, the cylinder and piston-guides must be strongly and exactly fitted, and it is very important that the bed-plate be massive

Massive bed-plate necessary.

and well fitted upon the foundation; and in large hammers, where it is necessary to make the bed-plate in several pieces, they should be so closely fitted and held together by bolts or keys that they cannot be shaken loose. **Accurate fitting.** The standards or framing should be accurately fixed upon the bed-plate, and the cylinder and piston-guides placed exactly perpendicular, and attached in the closest and tightest manner. **Piston-rods.** By constant percussion, the piston-rod and tup become crystallized, and these parts have periodically to be renewed.

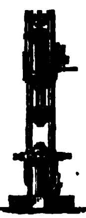
Manufacture of steam-hammers a specialty.

Since the main principles of the single and double-acting hammers were adopted, the manufacture of such machines has become a specialty, and a great variety of shapes and sizes have been devised for special trades and purposes.

Shape and size, how determined.

The shape or kind of steam-hammer is determined by the purpose to which it is to be applied; first, in regard to the mass or weight of iron to be dealt with,—the strength of the framing and area of the piston being so decided; secondly, by the form and dimensions of the forgings, which render a certain shape of machine preferable or necessary. **For repetition work.** Where the hammer is to be applied to articles of a repetition kind, as is often the case in special trades, the machine may be made to accord very exactly with its work; **For miscellaneous work.** but where, as in an engineer's factory, miscellaneous articles have to be forged, then, in order to admit them, more latitude must be left in regard to the shape, size, and situation of the machine.

Stamp-hammers of a special kind are used for forging small articles in dies. These stamps are compact in shape, have cylinders ranging in size from 5 in. to 15 in., and cost from £60 to £300.



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Stamp-hammer.

It is impossible to enumerate the great variety in detail of machines made according to the foregoing plans, the differences being sometimes only in regard to the pattern or arrangement of the parts, and sometimes in regard to the valve-gear.

Boilers for steam-hammers.

The size or capacity of boiler required for a steam-hammer depends mainly, as in a steam-engine, on the diameter and stroke of piston, the degree of expansion or cut-off adopted, and the average number of strokes per minute. **Capacity, how determined.** The latter circumstance is of importance, because while in a steam-engine the boiler must be of a size able to generate steam for continuous working, there must almost always in the working of a steam-hammer be intervals of rest, during which steam is being generated in the boiler.

Boiler must be as large as for an engine.

But, on the other hand, a hammer generally consumes more steam than an engine in the same time, as the steam is seldom cut off to

work so expansively, and the strokes of the hammer are often more rapid. Moreover, the hammer-valve is opened and shut so suddenly as to render the boiler more liable than an engine-boiler to priming. For these reasons, and the advisability of having always ample power at command for heavy forgings or those requiring long hammering at one heat, boiler power less than that for a non-condensing engine of similar cylinder-capacity should not be adopted without full consideration of the circumstances.

Anvils for steam-hammers.

The anvil has to be fixed with great care under a steam-hammer, so as to receive the blows fairly and in a right line. Sufficient weight and solidity to absorb the blows are afforded by heavy anvils, and in the larger machines elaborate and costly foundations are necessary. Stone or large masses of concrete are used as a basis, but generally timber is placed immediately below the anvil base-plate to afford some elasticity to the blow; this plan reducing greatly the destructive effect of the blows, both on the anvil and the foundation beneath it. The timber (oak or pine are usual kinds) is laid horizontally, as there is little elasticity in vertical baulks, but sometimes where the ground is loose, piles are driven to make a solid foundation below. The timber is carefully adzed or planed to afford a true bearing for the anvil. Special machines have been devised for planing the bed-plates after they are fixed; and in the case of the larger hammers, temporary furnaces have even occasionally been erected at or near the hammer, so that the anvil and base-plate, too large to be transported, may be cast *in situ.*

Foundations.

See pages 62, 69, 34.

Timber foundation.

Planing of bed-plates.

The purchase of hammers.

The principal points to notice in comparing prices of steam-hammers are the diameter and stroke of the cylinder, the actual dead weight of the falling parts (the rating of different makers may not be on the same basis in this respect); the accuracy of the fitting in all the jointed parts; whether the bottom of the framing is planed where it fits upon the base-plate; whether the base-plate is itself planed; and the material of which the tup or hammer is made. Wrought-iron or steel is best, but cast-iron has often to be used for hammers rated above 20 cwt. because of the expense. In small hammers the endurance depends also on whether there are slides or guides to the hammer-head, whether the anvil is separate from the framing, and is machined to fit exactly into the base-plate.

Prices compared.

Material.

Arrangement of parts.

Cheap hammers often defective.

Hammers made too cheaply are often defective in some of the above points, and their rapid deterioration far more than outweighs any saving in first cost. Cheapness is sometimes obtained in small

hammers by casting the framing and anvil-block in one piece; and sometimes also by making the cylinder and the framing in one piece, without any guides for the piston-rod.

Forging-machines. In a description of steam-hammers, reference may be made to forging-machines driven by wheels or belts. Such machines consist generally of a series of stamps worked by cams or eccentrics, and capable of giving from 500 to 800 blows per minute. In the making of small light forgings, such as those for fire-arms, machines of this sort are very useful for reducing rapidly the size of the pieces of iron presented to them. In other cases small forgings are shaped in dies by a few blows from a falling tup, which is lifted by a power-pulley to a height and at a speed determined by the workman, who pulls a lever for each blow.

For light forgings.

Small forging-machines. The shape of the various stamps can be varied, so that the smith has in effect a variety of tools to work with; or by placing the forging below each stamp in turn, it may be brought down to the required size. Machines of this sort range in price from £100 to £200, and require about one-horse power to work them.

Choice of steam-hammer, how determined. The most appropriate steam-hammer for any particular purpose can be designed or chosen only on the basis of the following information.

Purpose. 1. The nature of the trade and the average and maximum size and weight of the forgings to be made. If the forgings are, in regard to shape and size, to be constantly alike, a hammer may be specially designed to suit them.

Arrangement of smithy. 2. A plan of the smithy showing the doors and windows, the various hearths, furnaces, cranes, and other accessories, or the places available for them; also the capacity and position of the boiler for supplying the hammer with steam, or the direction from which the steam-pipe will be brought. If it is difficult or inconvenient to have steam boilers, the hammer can be worked by compressed air brought a considerable distance from an air-compressor, which may be worked as well by water as by steam. Not only a plan but a vertical section of the smithy should be supplied, showing the height available. It is obvious that information on these points is needed, to allow of the valve levers being put in the most convenient places; and to afford the most convenient access for forgings and for the erection of the necessary cranes.

Steam or compressed air. *See page 86.*

Height of smithy.

Foundations. 3. The nature of the foundations on which the hammer and

anvil are to rest, or of the soil upon which a foundation is to be made, and the solidity of the walls of the smithy and neighbouring walls to resist concussion. If there is no suitable stone in the neighbourhood, the expediency of sending with the hammer cement for making concrete, should be considered.

See page 351.

See page 334.

Transport.

4. The facilities for transport, and the maximum size and weight of the pieces that can be carried to the site.

See page 35.

Steam-hammers in cities.

5. The likelihood of objection to the hammer on the score of nuisance. The noise and concussion may be minimised, but the working of large steam-hammers is sometimes entirely prohibited in the central parts of large cities.

Circular saws for cutting iron or steel.

Circular saws for cutting hot bars of iron are often useful in engineering factories, though they are made principally for rail and bar-iron rolling-mills. The saws are of high-quality steel, about 30 in. diameter, and run at a velocity of from 1,200 to 1,500 revolutions per minute. In some cases the bars to be cut are moved against the saw; in others, the framing which carries the saw is swivelled and the revolving saw moves forward against the bar.

Hydraulic smithing-machines.

Hydraulic smithing-machines are better suited than steam-hammers to some of the processes of fashioning wrought-iron into shape while hot, the steady pressure of a hydraulic ram having an effect quite unlike that of the percussion of a steam-hammer on an anvil; and by applying the hydraulic force through the medium of an accumulator, an instantaneous action is obtained which pumps alone would not afford. Forgings of awkward shape, expensive to make on the anvil, may be pressed with advantage; and besides these the flanging of the end plates of boilers and the bending of T or L iron stiffeners for girders or ships' frames, exemplify the kind of work to which the hydraulic press is applied in a smithy; and by means of dies or swages the same press can be adapted to a great variety of shapes. As with a working pressure of 2,000 lbs. to the square inch a ram of 9 in. diameter will exert a force of 50 tons, it is obvious to what important uses such power can be applied. A machine of moderate dimensions exerts with the above-mentioned pressure a great force, and the pressure, though much higher than that adopted for certain purposes (700 lbs. is usual for hydraulic cranes), is free from the inconveniences which often attend in other hydraulic machines the use of still higher pressure. A 50-ton press with a stroke of 1 ft., complete

Accumulator.

See page 82.

Examples of use.

Working pressure.

Cost of hydraulic machines.

with pumps, accumulator, and pipes, but exclusive of motive power, dies or swages, costs about £400. If the pressing operation is only performed thirty times per hour, an engine of 3-horse power would suffice for pumping, or that amount of power would be abstracted from a line of shafting running for general purposes. Hydraulic presses may be used in combination with the steam-hammer, giving the final and exact shape to forgings hammered approximately into form, or may be used for "upsetting" a forging which is afterwards finished under the steam-hammer. This combination of methods is well exemplified in the manufacture of links or "eye-bars" for bridges, more usual in America than in England.

Hydraulic and steam-power combined.

Hydraulic squeezing.

For some of the purposes to which hydraulic smithing-dies are applied a slow squeezing motion is the best, and such machines have generally been worked by pumps without the medium of an accumulator. There is the disadvantage in this plan that small pieces of iron (less than 30 lbs. weight) cool too soon and cannot be treated successfully, while if an accumulator were used, the operation is completed before the iron cools. But for forging small pieces in dies small power-hammers are generally preferable.

[*See also* THE ESTABLISHMENT OF FACTORIES : THE TRANSMISSION OF POWER : MACHINE-TOOLS.]

CHAPTER XXV.

CRANES. STEAM CRANES. HYDRAULIC CRANES.

PUBLIC works and the transport of merchandise on the scale of the present day are only rendered possible by the cranes which are available; and their manufacture ranks with that of machine-tools as one of the principal trades on which engineers depend. The catalogues of manufacturers sufficiently enumerate the various kinds of cranes that are made for ordinary purposes and for moderate weights; but the diversity which affords so wide a choice to the engineer is, in itself, often a cause of difficulty for want of some analysis of the different methods employed, and of the special circumstances which, in particular cases, make one kind rather than another applicable.

Cranes enumerated in catalogues.

Difficulty of choice.

The various lifting apparatus included in the generic appellation of *Cranes* may for convenience be first divided into three principal categories, as—

Cranes classified.

1. Derricks and sheers.
2. Jib cranes.
3. Overhead cranes and travelling gantries.

Even these broad distinctions—though embracing the great majority of hoisting apparatus—are insufficient, for there are hybrid cranes which come partly within each; and there is also the necessary

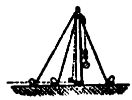
Hybrid cranes.

classification according to the motive power, manual, steam, or hydraulic. Moreover, cranes of whatever kind, if for lifting weights over 20 tons, need separate consideration, as also do portable as distinct from fixed cranes.

See page 376.

Derricks.

The simple *Derrick*, which is the most primitive kind of hoisting apparatus, may be considered rather as a substitute than as in itself a crane, and it is seldom used except for such temporary work as the lifting into place of girders or roofs. And although for such purposes, the weights lifted seldom exceed 10 tons, weights as heavy as 50 tons may be lifted by one derrick-mast or baulk of timber, if occasion requires it. The use of the single derrick is greatly limited by the necessity of keeping it nearly vertical, a condition which, indeed, puts it outside a strict category of cranes. The ordinary derrick is a spar or mast, square timbers being employed only where a round mast cannot be conveniently obtained. A fir scaffold-pole suffices for light weights and moderate lifts; a bundle of such poles is often lashed together to form a longer or stronger derrick than a single one affords; but it is always better to have one strong mast than such a compound substitute.



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Light-pole derrick.

Stability depends on guy-ropes.

Power from winch.

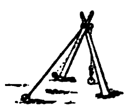
While the load is supported by the mast or pole, the stability of the apparatus depends entirely on the guy-ropes, of which there must be at least three. The hoisting power is obtained from a crab or winch, which for safety to the workmen, should be at a distance of not less than the length of the derrick, and the chain from the winch-barrel is taken through a snatch-block at the foot of the derrick to a set of sheave-blocks at the top, the power being multiplied and the speed of lift diminished in the usual way according to the number of pulleys. A derrick is often used in the erection of structures because of its portability, and while it is movable, the winch may be kept stationary, the chain being led in various directions by pulleys and snatch-blocks. An ordinary hoisting-crab or winch for working by hand costs from £5 to £20, according to its power, but if equipped with a steam-engine, from £60 to £100, and if with a boiler also, the prices range from £100 upwards.

Portability.

Cost of hoisting-crabs.

See also page 368.

When two poles or masts are used, the name of *Sheers* is generally substituted for that of derrick; two guy-ropes only are needed; the sheers may be inclined; and by altering the inclination they may serve, to some extent, the part of a moving jib or wharf-crane in transferring goods which are being hoisted, thus bringing the apparatus within the definition of a crane. As the sheers have lateral stability,



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Sheers.

one guy-rope before and one behind suffice, but if, as at the end of a jetty, there is no place for a forward guy-rope, then a pole must be substituted for the hinder guy-rope. Sheers of this sort are sometimes preferred to fixed cranes where hoisting has seldom to be performed, because the apparatus is cheaper and can be more easily removed than a crane. Except for the simplest cases and for very small weights, the winch gear is entirely separate from the sheers. For there is not much room on the sheer legs for a barrel or drum of proper size, and a small barrel is to be avoided if possible.

Advantages.

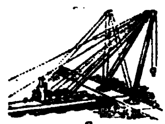
See page 363.

How made.

Derrick-poles and sheers are generally made by the user from the most suitable timber obtainable in the locality, the winch, chain, snatch-block, and set of sheave-blocks, which complete the apparatus, being separate articles to be purchased. The best pieces of timber are generally selected for derrick-poles, and the price rapidly advances with their size, so that when a mast 25 ft. long could in England be purchased for 2s. per cubic foot, one 50 ft. long would probably cost 3s., and one 70 ft. long 4s. per cubic foot.

Price advances with size.

The principle of the derrick and sheers has been elaborated in various ways and adopted for different kinds of permanent cranes. Lofty sheers for the masting of vessels are a notable example, as also are those (generally formed of three masts) used at docks for hoisting pieces or packages weighing more than 20 tons into ships. In these masts the cranes are generally made of hollow wrought-iron, and are hinged at the foot, so that the inclination can be so altered as to transfer the load from a ship's hold to the landing-quay. This can be performed by pulling back the foot of the hinder mast by a horizontal screw moved by a steam-engine, or, where there is not sufficient ground space available for the horizontal method, by pulling the foot of the hinder mast down below the ground level, as into a well. But as by neither of these methods is the hinder member of the derrick pulled directly in the desired line, a third method has also been adopted, by which the pulling-back force is better applied.



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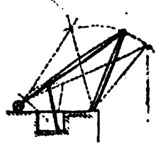
Permanent sheer-cranes.

See FRONTISPIECE, *Part I.*



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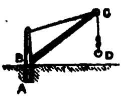
Cranes with projecting jibs.

The great majority of cranes are those with projecting jibs, the name of crane, indeed, originally having been given to apparatus of this kind. The various types now in use may be best described by classifying them according to the method of giving stability to the jib. On this depends, to a large extent, the general construction of the cranes; and as the choice of crane depends mainly on the local circumstances which may make one method rather than another pro-

fitable or convenient, it is one of the leading points to be considered. Assuming that the vertical post of a crane has a bottom pivot on which to rest and turn, the stability to withstand the leverage of the jib when pulled downwards by a load is obtained either—



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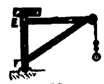
(*a*) By continuing the vertical post to a pivot A, so low down that it can, as one end of a lever A, B, C, working on the fulcrum B, withstand the downward pull at D. The post may either revolve on its pivot, or, as is more usual, the lower part of the post may be fixed, and the crane made to turn on it (Fig. 191).



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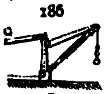
(*b*) By holding the vertical post at an upper pivot E as well as at the lower pivot F, the loaded jib being then supported like the end of a cantilever bracket.



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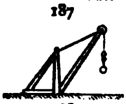

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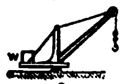
(*c*) By anchoring back the top of the vertical post either by means of a rigid backstay G to some independent structure, such as a wall, or to the ground, or to the base of the crane itself, so elongated as to afford a sufficient angle; or, if the distance be too great, or no convenient support for a rigid backstay be available, by means of wire ropes.



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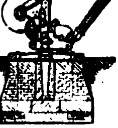
(*d*) By balancing the jib and its load by a weight W behind the vertical post, this method of counterpoise being often combined with methods *a* and *c*.

The advantages and drawbacks of the above methods may be further elucidated as follows:—The plan (*a*) of continuing the crane-post or the pivot on it which turns to a bearing below the ground is suitable for permanent wharf-cranes where no overhead support is available, the expense of the foundation being justified by the unobstructed space which is left at and above the ground-level. The depth of post which will suffice depends on the weight to be lifted. Thus, for weights up to 3 tons, sufficient stability may be obtained from one pivot resting on and revolving in a wide-base plate on the ground-level. A crane of this sort costs from £50 to £100. But for wharf-cranes of more than 3 tons capacity, the vertical post is generally taken down below ground to a depth of from 4 to 10 ft. Such cranes cost from £120 for 3 tons to £500 for one of 15 tons, but if fitted with steam-engine and boiler, these prices are more than doubled.



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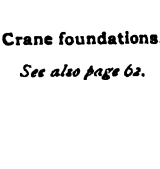

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Crane foundations.

See also page 62.

In good solid ground, a pit may be excavated, and an iron casting for holding the pivot built into masonry or concrete. Or, on loose ground, piles may be driven, a space excavated within and enclosed with sheet-piling, and a solid mass of concrete filled in below and around the ironwork of the crane. Or, groups of piles or cylinders

may be sunk, as in a bridge pier, and the pivot supported on cross-beams, which are sometimes then embedded in concrete. Occasionally, in difficult cases, such as in loose or marshy soil, the cost of foundations bears a high proportion to the cost of the crane, and renders the consideration of other kinds of cranes expedient.

Cranes on landing-piers.

See page 108, Part I.

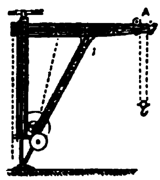
Where a crane is to be fixed on an iron landing-pier, a central cylinder may be braced to smaller surrounding cylinders or screw-piles and to the contiguous structure. It may be said generally that wharf-cranes are the most expensive kind of crane.

Cranes with an upper pivot.

See Fig. 186.

How supported.

(*b*) Cranes with a vertical post pivoted at the top as well as at the bottom are the cheapest kind when, as is usually the case, some existing structure is available for the upper support. Thus, in a foundry the crane is pivoted at the top to one of the roof-beams, strengthened and stayed for the purpose; in a smithy, to the wall; and in a warehouse or engineer's workshop, either to a wall or to a roof-supporting column. In the latter case, the column may serve as the crane-post, the horizontal jib of the crane grasping the column at a recess or neck made for the purpose. This arrangement somewhat resembles that by which a radial drilling-machine revolves on a column. Cranes held at the top of the vertical post are more suitable than any other kind for the horizontal jib which is necessary in a foundry or smithy to allow the moving carriage A from which the load is suspended to be traversed or "racked" in and out—a most important and necessary operation where the crane is so employed. For, if a crane have a slanting jib, which is generally the case in classes *a*, *c*, and *d*, the radial distance of the load from the vertical post can only be altered by raising and lowering the jib—a method which, though sometimes appropriate and convenient in a wharf-crane, is quite unsuitable where the traversing must be exactly regulated without alteration in height. In foundry-cranes the winch-gear and chain-barrel are attached to the vertical post, and hand-power is generally employed, although for lifting heavy weights a steam-engine can be attached or hydraulic power employed. Foundry-cranes are are often made of wood, and range in price from £100 for a 4-ton crane to £200 for a 10-ton crane. If made of iron, the cost ranges from £200 for a 5-ton crane to £500 for a 20-ton crane.



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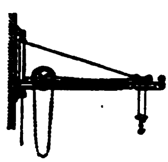
Foundry crane.

See page 358.

In a smithy-crane, for weights up to 5 cwt., winch gear is seldom employed, hand-power being sufficiently multiplied by sheave-blocks suspended from the travelling-carriage. For large smithy-cranes—those, for instance, which are adjuncts to steam-hammers—the power



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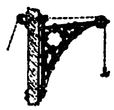
Smithy-crane.



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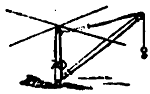
Warehouse crane.

is generally brought from the outside, either from steam-driven winch-gear or hydraulic apparatus, and is led through guiding-pulleys to, and along, the horizontal jib. A similar plan is also usual for cranes of this class used in warehouses and workshops; small water-engines or gas-engines being often employed as motors. Light "whip" cranes for lifting weights up to $1\frac{1}{2}$ tons are often made on this plan.

See Figs. 187 & 188.

(*c*) Stability of jib afforded by one or more stays anchored to a fixed structure or to an elongated base has the advantage of making the crane independent either of insertion in the ground on a solid foundation, as in method *a*, or of an upper support, as in method *b*. Indeed in some cases rigid struts are avoided, and the space they occupy saved, the staying being entirely by iron or steel wire-ropes, and if points of attachment are available on every side, the jib may revolve freely. This plan is often adopted in America for cranes elevated on lofty staging, distant supports being then available for the wire ropes. But in England, rigid struts or stays of timber are preferred, and the horizontal or inclined backstay may be anchored to a tree or wall; but as convenient points of this sort are not often available, it is more usual to anchor the back members to the base of the crane itself, prolonged for the purpose. Cranes of this sort are very useful on public works where a temporary hoisting apparatus is required, or one which can be moved from place to place; and they are also convenient where, from the loose nature of the ground, foundations would be difficult; or where, as on a landing-jetty or elevated staging, there may be nothing above or below the platform for supporting the vertical posts. Subject to various modifications, the cranes are made with two, and sometimes three, horizontal members framed together, and so extended as to afford points of anchorage for two inclined back members, E, F; the upper pivot of the vertical post being thus stayed with a favourably wide angle at A. Such a crane has in itself sufficient stability for moderate weights; but when heavy weights have to be lifted it is usual to increase the stability by loading the base members either by the weight of a steam-winch and boiler, or with stone or kentledge, or by tying them to the ground, additions of this kind bringing the crane into category *d*. The inclined jib is hinged at the heel C, so that by means of the back-chain B, which holds it to the vertical post, it can be raised or lowered to alter the radius. The lifting-power becomes greater as the point G is drawn back, and the process of lifting may be, and often is, partly performed by thus drawing



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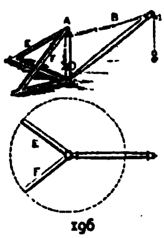
Cranes stayed by wire-rope.



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Temporary crane for public works.

Lifting-power according to angle of jib.

back the jib. As will be seen from the plan, a crane of this sort commands a radius of three-fourths of a circle; but in practice it is seldom effectual for more than two-thirds—a range wide enough for the majority of purposes; and the design of the crane and the disposition of the stays must be such as to afford sufficient stability for any position of the jib. Cranes of this sort are often substituted with advantage for overhead travelling cranes or gantries, compared to which they are—especially on elevated stagings—generally cheaper and more convenient. These cranes are extensively used, they command a wide area, have a high lift, the radius can be varied, and the cranes are cheap. They have, however, the inconvenience—which sometimes prohibits their use—of occupying much space. The prices range from £50 for a 1-ton crane with 25 ft. radius to £140 for a 5-ton crane with 35 ft. radius. If an engine and boiler be added (which may be utilised as a balance-weight) the prices would range from £180 to £450.

Range limited.

Used instead of travelling crane.

Occupy much space.

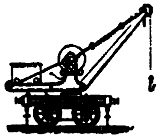
See page 366.

(*d*) Stability of jib afforded by a *Balance-weight* is one of the commonest methods, and is especially useful in a movable crane where no permanent anchorage is possible. The winch-gear is so placed that its weight is effectual, and in a steam-crane the weight of an engine and boiler, and sometimes also of a feed-water tank, is often added to make up the required stability. In stationary cranes the balance-weight may be permanently fixed, but where the crane is on a movable truck, as in a factory-yard or on a railway, the weight can be drawn inwards when travelling, and the jib lowered for passing under bridges or doorways. On a railway, of course, the width of gauge is established, and the crane-carriage must be arranged accordingly. As the length of the wheel-base is generally greater than the width, which is of course limited by the gauge, a crane stable enough when the jib is in a line with the rails may overbalance when projecting sideways, and anchorage to the rails may be necessary. But when the crane is thus attached, care must be taken that the permanent-way be not disturbed, and, if necessary, the rails must be weighted. Even the standard, or 4 ft. 8½ in. gauge, is not sufficient for cranes lifting more than 3 tons, without any other support than their own width of base and weight allow. But sometimes cranes are wanted on the mètre or 3 ft. 6 in. gauge, and such a width is insufficient even for the weight of the unloaded jib when projecting sideways, and the crane must be so propped or anchored during lifting as to be in effect a fixed or stationary crane. This is gene-

See page 60.

Width of gauge.

Cranes anchored down to rails.



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Cranes for standard gauge.

Cranes on narrow gauge.

rally effected by means of two light projecting girders clipped to the crane carriage and packed or propped at the outer ends, the packing-pieces being so arranged as to be readily withdrawn when the crane has to be moved. When the rails have to be laid down specially for the crane, a width of 5 ft. should be provided for lifting weights of from 2 to 5 tons; a width of from 8 to 10 ft. for weights of from 8 to 15 tons; 12 or 14 ft. for weights between 15 and 20 tons; and 16, 18, or even wider gauge for still heavier loads, although these gauges may be slightly narrowed if the full space is not available.

How steadied.

Strong cranes on wide gauge.

See also page 376.

Jib-cranes are made either of wood or iron, and even in cranes otherwise of iron, the jib is frequently made of wood, which is well suited to the compression and side-strains to which it is subjected. In beginning to lift a heavy weight, the inertia to be overcome causes severe side-strains on the jib, which, though strong enough to sustain the suspended load, might be twisted sideways and broken. Wooden jibs have been generally preferred for cranes up to 2 tons; between 2 or 8 tons wood or iron has been used; but for cranes of all sizes up to 8 tons iron is (1880) more frequently preferred than formerly. Beyond 8 tons any single piece of timber becomes too bulky, and for cranes between 8 and 15 tons it may be said to be now entirely discarded. But for very large cranes timber again becomes applicable. To resist the side-strains, a wide or box section of jib is most effectual, and for heavy loads an ordinary H or girder section would not be sufficient, and it is generally found cheaper to frame the jib of timber than to dispose an iron framing in a suitable manner.

Jib-cranes made of wood or iron.

Wooden jibs for small cranes.

Iron jibs.

Wooden jibs for very large cranes.

The lifting power in a crane is generally obtained by ordinary winch-gear, which multiplies the original motive force by a train of toothed wheels. In small and simple cranes *single power* is sufficient; that is to say, there is one multiplication only, a small toothed wheel or pinion on the spindle to which the winch-handles are attached, working into a larger wheel on the shaft which carries the barrel. This method is, for instance, sufficient where the power is afterwards multiplied by sheave-blocks, as in lifting by a derrick; but for weights above 2 tons, *double power* in the crab becomes necessary, a simple movement changing the wheels from single to double gear, according to the weight to be lifted. Of course, for every multiplication, the speed becomes less, and it is only in the case of very large cranes that a third multiplication is attempted, an increase in the original

Single-power cranes.

Double-power.

motive power being generally preferred. And even in large cranes where treble gear is provided, it is reserved for heavy loads, and the single or double gear is ordinarily employed. Sometimes the power is multiplied by passing the chain, after it leaves the jib, through single, double, or treble sheave-blocks; but this method, though often necessary, has the disadvantage of increasing the length of chain to be wrapped round the barrel, and therefore rendering necessary two or more laps of chain, which is undesirable.

Treble gear.

Power increased by sheave-blocks.

It is important that the barrel should be of ample size, primarily because a rope or chain winds most easily on a large drum, and (in the case of a chain) with less strain or surging in the links; and, secondly, because it is desirable to have the drum so long and large that a single lap of the chain, repeated if need be all along the barrel, may afford sufficient length for the highest lifts. For as the drum is one of the train of wheels by which the motive power is multiplied, the alteration in its effective diameter, which takes place if a second lap of chain occurs, alters the proportion of the wheels. As the circumference of the barrel becomes greater, each revolution gives a greater lift, and the motive power has to be proportionately increased. This is especially inconvenient in the case of hand-cranes, where there is not the same reserve force as in a steam-crane, and where the increased resistance caused by a greater diameter must be neutralized, either by a slower and less effective exertion, or by bringing into play in the middle of the lifting operation, another and slower set of wheels. Sometimes the lapping of the chain on the barrel is avoided by passing it only once or twice round and then taking it away behind, as is done often on a capstan, or into a pit below the crane; but as an iron chain on an iron barrel is apt to slip, the barrel must be tightly wrapped with rope to afford a grip for the chain, or made with projections to hold the links, as is done with pitch-chains.

Winding-barrels.

Made large to avoid lapping of chain.

Warping capstan.

See pages 68 & 370.

See page 111.

Of course, where the chain is but small—for instance, in cranes lifting about 1 ton—the lapping of a light chain will not materially affect the diameter of an ordinary-sized barrel; but, as a rule, the apparatus is distinctly the better if the lapping can be avoided. Obviously also, much depends on the height of lift, which determines the length of chain; but, if circumstances allow it, the condition of a single lap is often prescribed by engineers in their specifications for cranes, such a stipulation, however, adding considerably to the cost of those of over 10 tons' capacity.

Single lap on barrel.

For lifting weights over 25 tons, numerous trains of wheels may be avoided by substituting screw and worm-wheels for the ordinary spur gear; and worm-wheels have the advantage—which is useful sometimes also for smaller cranes—of lessening the liability to slip or run down, and a weight can be lowered or adjusted with great nicety and safety. Another method of applying power is to detach the winch-gear from the crane altogether—a plan which allows the use of a large winding-barrel and gear, affords more room round about the crane for attaching and detaching the load, and the further advantage of allowing the chain from the winch-barrel to be led away and used for a variety of purposes and at a considerable distance. On board ship the winch may thus conveniently be kept separate, and the chain be taken to hoisting-gear attached to the ship's yards; or with still more advantage in public works, where derricks or sheers may be moved from place to place or elevated on scaffolds, and the chain led through pulleys and snatch-blocks from a winch permanently fixed in a convenient place.

Screw and worm-wheels instead of spur gear.

Detached winch.

As on ships.

See page 368.

The expediency of substituting steam or other artificial power for hand-labour depends rather on the speed of hoist and frequency of the operation than on the weight to be lifted, for, if time be granted, the weights dealt with by the great majority of cranes can be lifted by hand-power. In comparing manual with other forces, it must be taken into account that two men can work more effectively and safely and do more work proportionately than one man, because there are certain dead points in each revolution of the winch-handles at which the force is not advantageously applied. In designing cranes it appears better, therefore, to take as a basis of calculation two men as the unit of force. The usual radius of the winch-handles is 16 in., making a circle of 32 in. diameter, or a circumference of about 100 in., and, allowing 30 revolutions per minute, the handles each travel 250 ft. per minute. Assuming, further, that each man exerts during the whole revolution an average force of 30 lbs., or the two men 60 lbs., and multiplying this by the 250 ft. travelled, a total of 15,000 foot-lbs. is exerted, or nearly ½ horse-power. And if from this, one-third be deducted for friction of the crane itself, there remain about 10,000 foot-lbs. as the nett result of two men per minute. This equals a load of 1 ton lifted about 4½ ft. per minute, or 10 tons lifted about 5 in. But in applying such a calculation as the above, which is necessarily based on certain assumptions in

Power-cranes, where useful.

Compared with manual cranes.

Power as applied to winch-handles.

Foot-pounds per minute.

See page 160.

regard to the force applied to the handles, the number of revolutions, and the loss by friction, all of which are liable to variation, the special circumstances of each case must be taken into account. Strong men can exert much more than 30 lbs. if for a short and intermittent load, while for continuous work, with few opportunities for resting, a less result must be reckoned. In England, 25 lbs. per man is generally prescribed as the basis for calculating crane-power in the Government dockyards, but for continuous work even this should be reduced. In regard to the friction, every additional train of wheels or multiplication of power increases it. In powerful cranes the moving parts are heavy, and, after the highest skill has been used to design and make the parts in the most suitable manner, the force required to work them, even with no load suspended, is very great, three or even four men being required to work a 20-ton crane unloaded. Two men will suffice for loads of 5 tons, although it is usual to employ four men when the load exceeds 4 tons; but when two men have thus to work at each handle, they are less conveniently placed for exerting themselves. It is very dangerous to have a crane under-manned.

Manual power varies.

Friction of crane-wheels.

Friction of powerful cranes.

Steam-power has proved so effective and convenient for cranes that it is the exception to its use rather than the rule that needs justification. For lifting weights where, from the nature of the work or the infrequency of the operation, there is ample time to allow the men to work slowly and to rest frequently, hand-power is generally preferred. So also where continual adjustment is needed, as in a foundry-crane, hand-power is still generally employed. Or, even for a wharf-crane, if seldom employed, there may be no advantage in having steam-power, which might require the bringing of steam into cold pipes from a detached boiler, or the lighting of a fire in a contiguous boiler, and very often the keeping the engine in order by a skilled engine-driver. But where, as in a factory, the chain can be worked from some machine inside connected with a running engine, such power may be utilised with advantage. And, in very large cranes, the extra cost of a steam-engine may bear so slight a proportion to the total cost of the crane, and the operation, though infrequently performed, may be so important, as fully to justify the cost and time of getting up steam. Another point to be considered in choosing between hand and steam-power is, that the former may necessitate an extra train of wheels to obtain the required force, and this extra train adds considerably to the friction, and therefore to the unprofitable

Steam-power.

See pages 73 & 366.

Steam-pipes.

See page 73.

See page 167.

Steam-power for large cranes.

Hand-power involves too numerous wheels.

expenditure. It is speed rather than power which renders steam so useful, and steam-engines are employed more often for small than for large cranes. Thus, in the loading or unloading of a ship, steam saves much time, and therefore much money. The expediency of having steam-power may be to a great extent determined by the proportion which the time occupied in the actual lifting bears to that occupied in the shackling or preparatory work, and the unshackling after the lifting is accomplished. For if fifteen minutes is occupied in shackling or arranging the sling chains, it is of little consequence whether the actual lifting occupy one minute by steam or ten minutes by hand; but if the slinging and shackling occupy only one minute, then the speed of the steam-engine is profitably utilised.

Saving of time the chief advantage of steam-cranes.

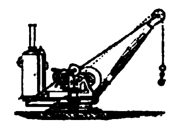
Steam-cranes.

For hoisting cargo.

See page 123.

See page 167.

Steam-cranes are used to the greatest advantage, in public works for the rapid and continuous hoisting of excavated soil or of building materials, and at docks for hoisting cargo into and out of a ship's hold. The speed with which all the operations of hoisting and lowering the load, of altering the radius by elevating and lowering the jib and of slewing round are performed, is so enormously in excess of what any hand-crane could perform, as to amply repay the greater capital expenditure and the current expenses of coal, supervision, and maintenance. The actual power is obtained much more cheaply by fuel force than by manual force, notwithstanding the fact that crane-engines burn more coal per effective horse-power than larger fixed engines. Except in special trades, most of the pieces or packages in a miscellaneous cargo are of moderate weight, and it may prove best to use light cranes which work easily and quickly, leaving heavy packages to be lifted by tackle from the ship's yards or, if over five tons, by powerful wharf cranes, to which the ship can be moved for the purpose. A steam-crane with a radius of 15 ft., complete with boiler, and with gear so arranged that the hoisting, lowering, and slewing are all performed by steam-power, will cost from £270 to £320 for lifting a weight of $1\frac{1}{2}$ tons; £350 to £450 for a weight of 3 tons; and from £450 to £600 for a weight of 5 tons. If a crane is to revolve on a fixed base, the foundation-plates and bolts will cost about the same as a carriage on wheels if the crane is to be made movable. If however the crane is to travel on a railway, the carriage and wheels must be stronger, and the necessary appurtenances of buffers and springs add from £20 to £50 to the cost. The power of a crane should be specified by the weight which can be safely lifted when the jib is projected to the full radius. The parts of a crane are sometimes so



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Prices.

See page 260.

made as to allow heavier weights to be lifted when the jib is raised so as to reduce the radius.

The small size of the engines and boilers, the quick speed and intermittent nature of the work all hinder an economical use of fuel; and as the cost of coal generally bears but a small proportion to the work done (which is not to be measured by the mere foot-lbs. lifted, but by many secondary considerations), the endeavour is rather to construct the boiler so that it will generate steam quickly, and with a minimum of size supply sufficient steam for rapid working, than to obtain a minimum expenditure of fuel. Vertical boilers with cross tubes are the kind generally used.

See page 165.

See page 167.

Steam-cranes severely strained.

The work of a steam-crane or winch is one of the severest kind, and the sudden stoppages and reversings cause jerks and shocks upon all the working parts. The value and durability of the machine depend greatly on the quality of the material and workmanship, and cheapness, if obtained by inferiority in these respects, is ultimately very expensive. Steel, the best wrought-iron, and high-quality cast-iron are essential, and all moving joints should be case-hardened. Steel, gun-metal, or malleable cast-iron are often substituted with advantage for cast-iron in toothed wheels.

See page 179.

Cargo cranes must be movable.

For loading and discharging ships, the cranes must be movable, so as to take various positions to suit the hatchways of vessels; and to avoid obstruction to the quay and to lines of railway upon it, the crane may be elevated on a travelling stage through which the railway wagons can pass. Movability is even more necessary for cranes used on public works. Therefore, cranes so employed must be complete and self-contained on a travelling carriage with engine and boiler. For wharf and other fixed cranes it is often convenient to bring steam from some adjacent boiler, and only the engine is attached to the crane itself, and though this plan is most easily adopted for fixed cranes, steam-pipes can be arranged for movable cranes also. Sometimes the plan of detaching the power is carried further, and the engine with its winch-gear and barrel is fixed in an adjacent building, and the chain brought to the crane through guiding-pulleys. This plan is often expedient in city warehouses or workshops, where steam-boilers, or even only an engine on the crane itself would involve risk and annoyance. In small cranes this plan is frequently adopted, the power from a constantly running drum near the crane being brought into action by fast and loose pulleys, or by a friction clutch, or other simple means. Where the boiler and its smoke are

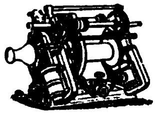
See page 370.

Wharf cranes made movable.

Engine detached from crane.

See pages 192, 194.

alone objected to, the power is often conveniently obtained from a gas-engine or water-engine. On public works, detached winch-gear, as already described, is often preferred, and on board ships a steam-winch with projecting warping capstan is in this way used for raising the anchor, warping cables, and other purposes, as well as for hoisting; but steam for such cranes is generally supplied from a detached boiler, or if in a steamer, from the engine-room. To afford equal and continuous power without a fly-wheel the engines for these winches are made with two cylinders, and with a link-motion for reversing. The cost of steam-winches of this kind ranges from about £80 for a winch with 5-in. cylinders for lifting 2 tons, to £130 for a winch with 8-in. cylinders for lifting 5 tons.



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Compressed air as power.

See page 86.

Compressed air is used for working cranes under certain circumstances, as, for instance, in places far from the source of power and whither steam could not be conveniently conveyed, or in tunnels or mines, where steam would be unendurable. This method is especially useful where water-power is available for compressing the air, or where air-pipes provided for other purposes are available. But where a steam-engine has to be employed to compress the air, the cost of this extra transmutation of force is of course only justifiable when circumstances render the direct use of steam inconvenient or impossible.

Air-power expensive.

See page 89.

Hydraulic cranes.

See page 75.

Hydraulic cranes may be used with advantage in many cases where any other kind would be costly, or inconvenient, or insufficient; and the facilities which water affords for transmuting, transmitting, distributing, and concentrating power, are seen to their best advantage in the case of cranes worked by the "accumulator" system. Where hoisting has to be done quickly, mechanical power of some kind is necessary, but if steam be employed and have to be worked at long or irregular intervals, much expense is involved in maintaining, ready for action in each crane, steam-power sufficient for the maximum service that may be required; and the useful or effective work done, bears but a small proportion to the power consumed, and to the expenses of supervision. And if, to save the cost and inconvenience of having a boiler at each of numerous cranes, steam be brought in pipes from one boiler, the pipes become cold during each interval of waiting, there is waste and inconvenience from condensed steam, and if this method were adopted for numerous or widely distributed cranes, the aggregate length of steam-pipes would be an insuperable difficulty.

Accumulator system.

See page 82.

Objections to steam-power.

See page 74.

The hydraulic system obviates all these objections. A pumping-engine, of force equal to the average service constantly employed in raising the accumulator, stores up a power which can be drawn upon instantaneously by any crane which has been connected by pipes within a mile or more of the pumping-engine; a crane, for instance, in some remote place, required only once a day or once a week, being as readily set to work as others. The loss of power in transmuting steam-power into hydraulic force, and in keeping a pumping-engine always in steam, is more than met by the conveniences afforded; and stationary engines so employed can be worked with the minimum of fuel, 3 lbs. per indicated horse-power per hour as compared with 10 lbs. in a steam-crane, being a fair comparison. The system finds its best exemplification at railway goods-stations, where rapid work at numerous cranes is required, but at irregular intervals; or in factories where the accumulator system is utilised on a wide scale for working machine-tools.

Avoided by hydraulic power.

Fuel consumption. *See page 162.*

Cranes at railway goods-stations.

A steam-engine fixed in some convenient place is employed in pumping up the accumulator load, which, pressing on the water uniformly in all the lines of piping, keeps ready at each crane the maximum force. The engine is arranged so as to stop pumping automatically when no power is being abstracted; and if, on the other hand, at any particular moment, all or most of the cranes happen to be lifting simultaneously and more power is sought than the engine affords, there is only a brief delay till the engine accumulates the necessary force and supplies the demand upon it. And if there be only one or few cranes, or only occasional service required, there need be no special steam-engine if there be a line of shafting from which a small pump for the accumulator can be driven; or still further economy may be obtained if moderate but continuous water-power be available for working the pump. Another advantage of the hydraulic system is the great power which may be obtained in cylinders of small size, the ordinary pressure being so much greater than that usual in steam-engines.

One pumping-engine works many cranes. *See page 82.*

Pumps worked from shafting.

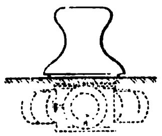
Customary pressure.

At each crane, the power is applied by means of a cylinder, moving-ram, and sheave-blocks, to which the chain is attached; but instead of multiplying the power as is usual in a crane, the high-pressure water affords so much power that it can be diluted by means of sheave-blocks worked in the reverse way to the ordinary method. That is to say, a ram, with a stroke of 4 ft., pulling at a pair of three-sheave blocks, drags the chain which issues from the last pulley

Mode of working.

Speed increased.

24 ft., but, of course, with a power proportionately diminished. In a large terminal railway station, with numerous cranes for loading and discharging the trucks, cranes so worked are extremely convenient for weights of from 5 to 40 cwt., and can be managed by ordinary workmen, who have nothing to do with the motive power at a distance, but who can control the crane by pulling a lever. The high-pressure water can also be applied with advantage to small engines (three-cylinder engines are found most suitable) which, placed below the platform, give motion to capstans for shunting and marshalling the wagons, as a rope passed a few times round the capstan can be instantaneously pulled with great force.



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See page 175.

See page 83.

A pressure of from 500 to 700 lbs. per inch has (1880) been adopted for hydraulic cranes as just described; but the apparatus could be as well worked at 1,000 lbs., if occasion demanded, without involving the modifications in detail or special precautions which much higher hydraulic pressures would require. The distributing pipes for the hydraulic system are of cast-iron, of sufficient thickness to withstand the pressure, and united by strong flanges and bolts. A ramification of such main pipes and branches, laid down in and about a railway station, or factory, or dock, allows of cranes or other machines being connected at any point at any time, if the main pipes are made large enough in the first instance to transmit the water required.

Hydraulic pipes and tubes.

See page 236.

See page 272.

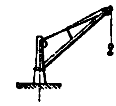
Hydraulic system expensive.

The capital outlay for hydraulic cranes often forbids their adoption, especially in small undertakings, where the saving to be obtained in the current expense of working would be doubtful or not immediately apparent. As the light cranes for unloading general merchandise are easily worked by hand, it is only at large or busy stations where many such cranes are required, that the expense is justified. The system has been widely adopted in England, because the enormous goods-traffic at the principal railway stations must be quickly moved. A complete establishment consists of steam-engine, with boilers, pumps, accumulator, and the necessary adjuncts of engine-house, boiler-house, and chimney; cranes, each with a cylinder, ram, pulleys, and chains; and the lines of pipes and valves. As a safeguard against stoppage, it is generally expedient to have duplicate engine, boilers, and pumps, which add considerably to the expenditure. Hydraulic cranes of the kind usual at railway stations, with ram, pulleys and chain for lifting about 30 cwt., cost from £100 to £150 each, the exact sum depending not so much on the hydraulic apparatus as on the projection of the jib, the height of the crane-post, and whether

Where justified.

At large or busy railway stations.

Duplicate engines.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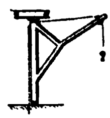
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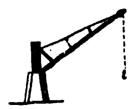
Jib cranes.

See a and b, page 358.

Gas-engines for pumping.

See page 192.

the crane is made according to the method *a* or *b* (Figs. 185, 186). Method *a*, in which the crane depends entirely on a lower pivot, and which is that usual on a wharf, is the dearer, method *b* being more often employed in warehouses, and sometimes in goods-stations, where overhead roof-beams are available for support and attachment. The establishment of hydraulic cranes, including engines, buildings, and pumps, ranges at different railway stations from £4,000 to £30,000, a cost which is prohibitory in most private establishments. Where the service required is infrequent or of small extent, much of the expense of steam-engine and boiler may be avoided by the use of a gas-engine, with pump and small accumulator, which are set in motion only at the time when the machinery is needed. This method is, for instance, occasionally adopted for such intermittent service as the opening machinery of swing-bridges.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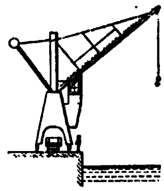
Movable crane for docks.

How worked.

The great convenience of having the accumulator system established in a dock for opening and shutting lock-gates and for warehouse hoists, as well as the objection to steam-cranes because of the risk of fire, has tended greatly to the adoption of hydraulic cranes also, and those of moderate lifting power have proved most suitable for miscellaneous cargo, the apparatus being arranged for high speed. As cranes of this sort must command the hatchway of a vessel, the radius of the jib must be greater than that of a railway goods-station crane, and must have a much greater height of lift and length of chain so as to raise cargo from the bottom of a ship's hold, and swing it clear of a railway wagon on the quay. And also as such a crane must be self-contained without upper support, it is necessarily more expensive than one of similar power attached to a roof beam. Owing to the differences in the size of ships and in the position of hatchways, fixed cranes have proved inconvenient, but the other advantages of the hydraulic system lead to its adaptation to movable cranes rather than its abandonment. There are two different methods of effecting this. As only a limited range of movement is necessary to allow the crane to be placed opposite a ship's hatchway, the power-chain can either be led through pulleys from a fixed hydraulic ram in a contiguous building, or the hydraulic apparatus, being affixed to the crane in the ordinary manner, the water-pipes from the pressure-main can be so arranged with telescopic or swivelled joints as to allow the necessary movement of the crane. To afford sufficient stability to the overhanging jib, the crane carriage is best made with wheels for a wide gauge, a third line being laid

down on the ordinary railway track, the base of the crane then being rather wider than shown in Fig. 203, and furnished with wheels. Fixed or movable cranes as above described, with a radius of 28 ft. from the centre post (about 23 ft. overhang from the quay), and for lifting 35 cwt., cost from £400 to £500 each.



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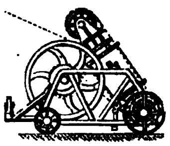
Elevated crane.

As movable cranes of this sort hinder the passage of goods-traffic on the edge of the quay, the system has been further elaborated by raising the crane carriage and making it wide enough to bridge over the railway on the quay, so as to allow hand-trucks to pass through. A crane of this sort requires a rail track of about 10-ft. gauge and a jib radius of 30 or 32 ft. from the vertical post to allow it to overhang the quay 23 ft., and such cranes are necessarily expensive, costing from £500 to £700, but this expense is justified by the rapid transfer of cargo to or from railway wagons which the system allows. Portable machines of a smaller and cheaper kind can be utilised wherever hydraulic mains are laid down in a dock. These small machines (known as jiggers), have a ram with sheave-blocks arranged on the same principle as in a hydraulic crane, but without any crane-post or jib. The goods are lifted from the ship's yards, to which the chain is taken from the machine. The height is arranged to omit the depth of hold, the lift of the chain being multiplied not only by the sheave-blocks but by the differential diameter of the barrel. A machine of this sort is easily propelled by hand and can be attached to a hydrant at any point along a dock or quay. They cost about £100 each.



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Portable hydraulic winches.

See also page 79.

While, however, cranes as just described are suitable for miscellaneous cargo, much stronger cranes are necessary at ports where heavy weights have constantly to be lifted. For instance, at some coal-shipping ports, loaded wagons of from 6 to 12 tons' weight are lifted and swung round over the ship's hatchway. For hydraulic cranes of this sort (as is the case generally for large cranes) special designs are required, and no fixed designs or prices apply.

See page 123.

Disadvantages of hydraulic cranes. *See page 84.*

The non-compressibility or want of expansive force in the water is a disadvantage in hydraulic cranes which has been already explained, as also the risk of stoppage from frost.

Travelling-cranes.

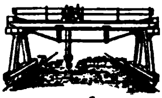
Travelling-cranes and overhead gantries, though made in various ways, form a class of their own entirely outside the cranes just described, the main point of difference being that the weight is lifted by, and suspended from, a bridge or girder supported at both ends,

instead of from a single column, as in a derrick, or from an overhanging jib in an ordinary swinging-crane. Full advantage is taken of the double support to extend the area commanded by the crane, the width ranging, according to circumstances, from 20 ft. to 70 ft.

Command wide area.

Fixed gantry.

The fixed gallows or gantry is the rudimentary type of overhead crane, a cheap and simple structure of this kind being sometimes used for loading and discharging wagons in a quarry, stone-merchant's yard, or boiler-yard, the articles to be lifted being brought to or taken from the gantry on rollers. It is a simple step forward to fix the uprights on a horizontal sill or base furnished with wheels, so that as a travelling-carriage it can be propelled along a line of rails laid down for the purpose, such cranes as these being known as Goliath cranes. A crane of this sort is cheaper than an overhead bridge moving on an elevated staging, and it leaves a clear space below except at one place where the crane is at work, such an unobstructed area being often of great importance. On the other hand, the fixed staging with a travelling-bridge affords a complete apparatus, more easily worked, and allows two or more travelling-bridges to be at work on the same stage.



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Goliath crane.

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Travelling bridge on fixed staging.

Timber is generally used as material for the staging and travelling-bridge, and timber beams trussed with iron tie-rods can be made strong enough even for wide spans and heavy loads. But wrought-iron girders are also frequently used for the travelling-bridge, and even as longitudinal supports for the rails on which the bridge works. In a factory, a set-off in the wall (208) affords such continuous support as to require only a longitudinal sleeper below the rails. Sometimes the girders or beams are carried on brick piers or iron pilasters (209) at short distances apart, or on corbels projecting from the wall, or on small brackets (210) cast on or bolted to the columns which support the roof. In engineering factories, it is important to allow ample headway under the crane, so that the travelling-bridge will pass clear of any lofty machine or structure that may have to be erected. The motive power is given in various ways. In the simplest cases, a rope passing over a grooved wheel, as in a whip crane, allows the power to be applied from below. Or, for small cranes and simple cases, an ordinary crab or winch is fixed on the bridge, with gear by which it may be made to traverse the bridge, the forward movement being separately performed by a simple gearing attached to one of the travelling carriages on which each end of the bridge rests. Sometimes, every movement is performed from below, the forward

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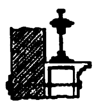

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motion of the bridge, the traversing of the winch on the bridge, and the lifting of the load, being effected by various clutches manipulated by the workman in charge. In powerful cranes, however, it is usual to have a steam-winch on the bridge, which not only serves for hoisting but for the traversing and longitudinal movement. In factories, advantage is sometimes taken of a fixed steam-engine to transmit power by a longitudinal shaft the whole length of the traveller, and, the shaft being square in section, the wheels which take power from it slide on the shaft as the bridge travels. Or, power is brought from a fixed engine by hempen or wire-rope, either of which, if run at a high speed, need be but of small diameter. By these means the lifting and other movements may be managed either from the bridge or from below, but in neither case is there obstruction from steam, or boiler, or winch-handles on the crane itself.

Steam-winches.

See page 111.

See Figs. 204 & 214.

Jib-crane raised on staging.

Another method of working is by the combination of the jib-crane and the travelling crane, as already described, the jib affording the advantages of rapid lifting and slewing, and the elevated staging allowing a clear space to be left below, this plan being especially convenient at docks where the quay would be obstructed if the jib crane were on the ground level.

Choice of crane.

Numerous patterns.

Large cranes need special design.

Temporary crane.

See page 356.

All the types of cranes that have been here described are made in various ways by different manufacturers, whose catalogues afford ample choice. But the diversity of design which the competition of makers affords, and which is available for cranes of moderate power, becomes rapidly less as the size and capacity of the crane increase. For in designing cranes with a capacity beyond 15 tons, every circumstance of locality or purpose acquires enhanced importance, and it is generally necessary or expedient to make a new or modified design. Large cranes are so expensive that the preliminary question of the permanence of the service should be fully considered, as temporary hoisting apparatus can generally be more cheaply contrived. Thus, in the case of public works, if large masses of stone or concrete have to be lifted during a short period; or in the establishment of a factory, the unloading of boilers; or at a fortress, of heavy guns, derricks might be cheaply erected and removed when the work was accomplished. As previously mentioned, loads even as great as 50 tons can be lifted from one mast or baulk of timber, the necessary adjuncts of guy-ropes, crab and sheave-pulleys being in themselves comparatively inexpensive. For unloading from a ship,

however, a single piece of timber would seldom be sufficient, without great risk and difficulty, and sheers formed by two masts would be necessary. *See page 356.*

Powerful permanent cranes.

If, however, the lifting of a heavy weight will periodically recur, then the capital outlay for a permanent crane becomes justifiable. Thus at a government dockyard or arsenal it is necessary to have a crane strong enough for the heaviest gun or armour-plate; and at a mercantile port where locomotives, large boilers, or guns are shipped or landed, one large crane is generally indispensable. And even on public works to be completed within a limited period, the time may be long enough and the operations so numerous within the period, as to amply repay, by the conveniences afforded, the greater cost of a permanent crane over that of temporary apparatus. At arsenals, dockyards, or mercantile ports, a wharf-crane is the kind generally required, and the expense of a self-contained crane according to method *a* is generally incurred. The kind and cost of foundations is then a question of great importance, but if there be great difficulty in regard to foundations then method *b* or *c* affords certain advantages. Jib-cranes are hardly ever made for loads above 25 tons, permanent sheers or derricks then becoming preferable.

At dockyards and public works.

Made as wharf-cranes.

See a, b, c, page 358.

Foundations.

See page 358.

Cranes for lifting concrete blocks.

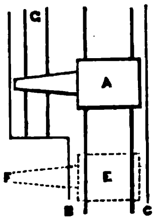
See CEMENT, *Chap. XXVII.*

Some of the most powerful cranes are those which have been designed for lifting concrete blocks in the construction of harbours and breakwaters. During the thirty years ending 1880, the size and weight of such blocks have tended to increase, and blocks weighing 30 tons are frequently made, and occasionally blocks of 100 tons and upwards. It is not merely the weight which determines the strength of the crane, but the necessity for a far-reaching jib or arm to deposit the blocks; and it is evident that the strain on the crane is in a rapidly increasing ratio to the load as the overhang and leverage become greater. Indeed, some of the machines constructed for lifting heavy weights are outside any ordinary category of cranes.

Far-reaching jibs.

Special cranes for heavy loads.

Engineers in designing harbours or breakwaters, finding that no existing kind of apparatus will lift, convey, and deposit the heavy masses with which they have to deal, design cranes specially for their purpose, not only in regard to the main points of lifting and traversing the load, but also to secondary points, which are of scarcely less importance. Thus, the crane must be placed so as to be easily accessible to the loads brought to it, and to deliver them conveniently on the desired spot; and the crane itself must be as little obstructive as possible. The greater and more extended the work to be done, the



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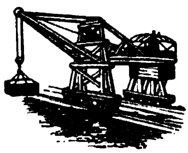
See VIGNETTE, *page* 355.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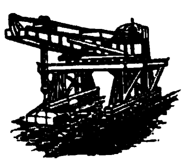
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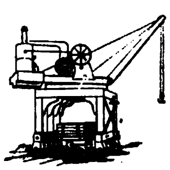
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Special cranes.

greater the expenditure which is justifiable. For instance, in the construction of a harbour or breakwater, a movable crane for depositing heavy blocks of stone or concrete may be so arranged as to be clear of the road or railway by which the blocks are brought to it, so that wagons may pass freely under it while the load is being lifted, traversed, and lowered into place. Thus a breakwater or sea-wall having been first made wide enough B C for a single line of rails, a crane A (212) moving on these rails may serve to lift concrete blocks brought within its reach either by water to the side of the structure, or by the railway G on the already widened part, and may then move forward to E to deposit them at F, so as to widen the structure along its whole length. Another form of crane (213), equally powerful, but more elaborate, is one of a hybrid kind, the lower part consisting of a travelling stage and the upper part of a movable crane which can traverse the whole width of the staging. A lifting machine of this kind is arranged for working at the end of a structure, building it forward into the sea; the wagons passing through from behind till the blocks they carry are within the grasp of the overhanging jib. The block of stone or concrete having been seized, the carriage on the jib from which the load is suspended is propelled forward, and the crane itself traversed across the stage till the block overhangs the desired spot, when it is lowered. It will be seen that these special cranes have only a rectangular motion, and are limited therefore to a particular range of duty. Jib-cranes revolving on a pivot or turn-table, and mounted on a travelling stage (214), while allowing the same unobstructed space below, can slew round in every direction, and are therefore suitable for more various purposes. But in a jib-crane of this sort there is the disadvantage that the load cannot be racked in and out as in a foundry crane, and the alternative plan of raising and lowering the jib is often inconvenient. As, however, a short range of such racking movement is sufficient in most cases for adjusting a load, the slanting jib may be prolonged horizontally for a few feet, and a travelling carriage placed upon it as on the jib of a foundry crane. Huge machines of the kinds just described for lifting weights of 25 to 30 tons, and depositing them from a jib overhanging 30 to 50 ft., cost from £2,000 to £4,000.

Cost.

Floating cranes of considerable power are often required in harbours and docks for use in cases where it is more convenient to bring the crane to the ship than the ship to the crane. Strong vessels are

needed to sustain such cranes, and while the stability depends primarily on the breadth of beam, the suspended loads are partly balanced by water-tanks or other counterpoise. A floating crane with jib projecting 20 ft. beyond the side of the vessel on which it stands, and for lifting loads of 20 tons, will cost from £6,000 to £8,000. In some harbours where vessels of deep draught cannot lie alongside a wharf, floating cranes or derricks are used for discharging cargo into lighters, but in such cases the cranes are usually of moderate power, and the peculiarity lies in the arrangement of numerous cranes on one hull as they might be on a wharf. Coals and similar bulk-cargo may be rapidly discharged from a ship to barges by numerous cranes fixed on a floating hull, and working simultaneously at two or more hatchways. A complete hydraulic equipment will generally prove best for rapid working. Grain in bulk is best lifted by "elevators," which have a series of buckets on an endless chain and ladder, something like a dredger; and, one end of the ladder being inserted in the hold, the buckets scoop up the grain and deposit it either on barges or into railway wagons on shore, or to the upper storey of a warehouse. These elevators are sometimes fixed on a floating vessel and sometimes on shore, and they are as well suited for delivering into a ship as from it.

Floating cranes.

Discharging coals.

Grain elevators.

To allow the selection of a crane best suited to the purpose in view, or to enable an engineer or manufacturer to make an appropriate design, some or all of the following points need consideration, the importance of every incident increasing as the lifting power and radius required become greater:—

Choice of crane, how determined.

1. The average and maximum weight of the articles to be lifted, and the relative frequency of each. If the maximum weight seldom occurs, it will be desirable, while providing the full power, to make the arrangements conform specially to the more frequent operations.

Power.

2. The size or bulk of the pieces to be lifted. The shape of the jib has often to be modified and made of appropriate shape, this point having to be considered in connection with the length or projection of the jib; and on this the resisting power of the crane and the strength and cost of the whole apparatus often depend. In connection with this point, it must also be considered whether the radius will have to admit of alteration, and the lifting power may be modified accordingly. Thus, a crane which will lift 12 tons at the extreme radius may be arranged so that it will lift 20 tons with a shortened

Size and shape of pieces to be lifted.

Altering radius.

jib. But directions as to the safe limits of loading should be conspicuously affixed to the crane, to prevent misuse and accident.

Kind and frequency of working. 3. The nature of the operations to be performed and their frequency, so far as will determine the expediency of steam-power and other arrangements for quick working. Any special circumstances, such as rapid working during certain hours of tide, should be considered.

Height of lift. *See page 363.* 4. The average and maximum height of lift for which a winding-drum and chain must be provided.

Fuel. **Water-power.** *See pages 83 & 370.* 5. If a steam-crane is required, the kind of fuel should be described; if hydraulic power, then the nature of the apparatus and pressure which is available.

Foundations. *See page 358. Also* JETTIES, *Part I.* 6. If for permanent use in one place, a plan of the site is useful in assisting the choice of kind and shape of crane. If a wharf-crane is required, the nature of the ground and its suitability for foundations should be described. If the crane is for an iron or timber jetty, a drawing of the structure should be furnished, so that the sufficiency of the structure to support the crane when loaded, or the method of strengthening it, may be considered.

Movable cranes. *See pages 260 & 361.* 7. If a crane on travelling-wheels is required, the width of the existing railway gauge, and the width and height permitted for passage through bridges. But if rails are to be laid down specially for the crane, the limit of width within which the gauge may be made to suit the crane.

Ropes and chains. **Steel-wire rope.** *See page 111.* 8. In cranes of moderate power, it should be stated whether hemp ropes, iron chains, or wire ropes are preferred, as the winding-drum as well as the sheave-blocks must be made accordingly. Ropes are not suitable if exposed to the weather, and for any but moderate weights are cumbersome and inconvenient. Steel-wire rope is now available as a substitute for chain or hemp rope, and offers the great advantage that it shows signs of deterioration, and is not, like a chain, liable to sudden fracture. But as wire ropes of various kinds and for various purposes are made, it is important that rope of sufficient flexibility should alone be employed. The manufacturer should be informed of the purpose for which it is required and the diameter of the barrel on which it is to wind. *See page 113.*

[*See also* FACTORIES: THE TRANSMISSION OF POWER: *and in* PART I., HARBOURS *and* DOCKS.]

CHAPTER XXVI.

EXCAVATING MACHINES. BORING-TOOLS. ROCK-DRILLS. DREDGERS. PILE-DRIVERS. DIVING APPARATUS.

Excavating machinery.

THE use of machinery for excavating earth, gravel, sand, and other material usually dug out by the spade, though often proposed by inventors, did not till about the year 1860 in America and 1870 in England, reach beyond experiment. Machine excavators and scoops had before then for many years been used for the sinking of wells, for bridge foundations, and for subaqueous dredging, these being cases where simpler methods were impossible.

Why used.

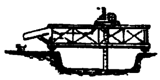
But the scarcity or high price of labour in some cases, and the great need for speedy execution of extensive works in others, drew the attention of contractors to new inventions which seemed likely to supersede or assist hand-labour; and even where none of these reasons would have sufficed, the saving in cost which the new machines were found under certain conditions to allow, ensured their adoption in the ordinary competition of trade.

Different methods classified.

There are several kinds of machine excavators, but they may be broadly classed as of three kinds, *i.e.*, those with a series of continuously moving buckets or scoops, as in a dredger; those in which one scoop or cutter is attached to an arm which forces it into the ground and digs out the soil; and those with hollow cutters or scoops, which being let down vertically, grasp the soil and bring it

back as in a bucket. To these must be added apparatus for excavating by air or water pressure, and also boring-tools, which, though *See page 386.* they penetrate to a great depth, are principally used for well-sinking, and are employed for excavation only as preliminary or accessory to larger operations.

See page 397. The experience gained with dredgers for subaqueous excavation where hand-digging is impossible, naturally led to the consideration of this form of machine when mechanical digging on dry land was required. So cheaply has subaqueous dredging been performed, and so skilful are the operators, that it has often been found profitable when a dredger-boat has been stranded at low water on a shoal or bank to continue working even although manual digging or other ordinary methods would have been possible. So that it appeared a ready method to construct a complete dredging apparatus on a stage travelling upon wheels instead of on a floating vessel. The machines of this sort that have been made resemble somewhat a travelling crane or gantry, moving forward upon a railway of from 30 ft. to 40 ft. gauge, and on the bridge or transverse platform is a steam-engine and upper framework for carrying the "ladder" with moving buckets like those of a floating dredger. The ascending buckets are emptied at the top into a horizontal carrier, which discharges into wagons at the side. In a case of this sort, the rail-track for the apparatus would be on the ground-level, and the stage, spanning the excavated space below, would work forward, the dredger buckets cutting into the solid wall in front as the machine advanced. By this means, a continuous cutting or gullet is excavated, which can afterwards be trimmed and widened by side-filling into wagons on a line of rails at the bottom of the cutting. It is obvious, however, that an apparatus of this kind could be arranged in various ways to suit particular cases, according to the depth of cutting, the levels, and other circumstances. In these respects, there might be as many varieties as in a floating-dredger, but the facilities which the water affords for supporting the machine at the desired spot, for moving from place to place, and for conveying the spoil, are wanting in the land-dredger travelling upon rails.



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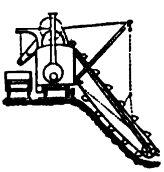
Land-dredgers.

Mode of working.

Not equal to floating-dredger.

Travelling land-dredgers can be made of a size small enough to move upon a railway of standard gauge, although when actually at work a third or outer rail would be necessary for stability; the width of base so obtained determining the angle at which the buckets could work. In the cases where this plan has been applied, the arm or



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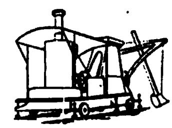
ladder is about 30 ft. long, sufficient for a cutting as deep as 15 ft. below the rail level at an angle of 45°. The buckets each hold about 6 cubic feet, and dig at a rate of about 20 buckets per minute. Machines of this kind are best suited for excavating sand or loose soil, or for loading up ballast into trucks. Much of the expense of working is in the continual moving back of the rails as the machine cuts away the edge of the bank.

Steam excavator on railway.

It is impossible to state the cost of excavating by travelling dredgers of the kinds just described, as so much depends on the subsidiary operations that have to be performed. When in full work, the saving over hand-labour may be undoubted, but the first cost of the machine, the expenses of fuel and attendance, the laying, maintaining, and relaying of the rail tracks, as well as the liability to delay from repairs, all add considerably to the outlay; and unless there be a very large amount of similar work to be done, these incidental expenses are generally prohibitory. The occasions when the land-dredger could be employed with advantage are therefore very rare, but so various are the circumstances which occur in public works that experience gained with such apparatus may be utilised when favourable conditions present themselves.

Land-dredger very rarely applicable.

The Steam-digger or *Steam-navvy* has most of the functions of a crane to perform. The machine is fixed upon a travelling carriage, and besides the steam-engine, crane-post, and jib, there is a projecting arm with an iron scoop upon it, which, by an ingenious combination of pulling, pushing, and lifting, cuts into the ground in front of it and scoops it away. To work effectively, the machine should be at the lower level of the excavation and cut into the solid wall of earth in front of it. Starting from level ground against a slope or hill in front, the machine cuts its way, forming a channel or "gullet" as it proceeds. The width of the gullet is determined by the radius or sweep of the jib and digging-arm, but it cannot cut at a steeper angle than 45°. A width of about 40 ft. has been found most useful, as it allows of a line of rails on each side of the machine, and, in the case of a railway-cutting, leaves only the trimming of the sides to be done by hand-labour.



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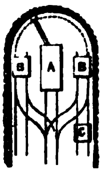
Steam-navvy.

Width of cutting.

These machines may be worked with either two or three lines of rail, according to the arrangements for supplying and removing the trucks, the rate of working and other circumstances. But where, owing to the nature of the ground, the machine can work quickly it is sometimes found expedient to lay three lines of rails. On the centre



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line (which must be of strongly laid rails to bear the weight) is the machine A, and, if need be, a line of empty trucks behind. The outer lines are about 3 ft. higher than the middle line, and serve for the trucks B, which are being filled, and for those C already filled waiting to be removed. Two men are generally employed to direct the machine; one man stands upon it, and, as in the case of a steam-crane, is able, by the various handles within his reach, to lift or lower the digging-arm or slew round the jib. The second man manages the scoop, which is made with a hinged lid or trap-door at the bottom by which the spoil is discharged into the wagons. Besides these two principal men there is a fireman; and in addition there are men to trim the sides of the gullet, to manage the wagons and the lines of rail. But as these duties have also to be performed where the digging is by hand, they may be excluded in comparing the cost of actual excavation. The scoop has a sharp steel lip, and will cut into stiff clay or gravel, even when mixed with boulders. The scoop is first lowered into the position shown, and cuts its way upward, and when it is clear of the surface and full of spoil, the jib swings round like a crane, and the scoop, being brought over a wagon, is emptied by the falling downwards of the hinged bottom. The scoops vary in size, and hold, according to the nature of the ground, about one cubic yard; and according to the stiffness of the ground, the sufficiency of wagons and other accessories, the machine will excavate from 400 to 700 cubic yards per day, or about the work of 40 able men. They have been successfully used for excavating chalk. The actual rate of work depends not only on the nature of the ground but on the efficiency of the arrangements for removing the spoil after it has been delivered by the machine.

Mode of working.

Rate of work, how determined.

Gullet widened by side-filling.

When the cutting or gullet has been made by the machine, the width of the cutting may be increased by side-filling into the wagons below. This course is convenient where the width of excavation required is greater than the machine can accomplish, and in excavations over a wide area, as in excavating a dock, a series of parallel gullets can be made, leaving only banks or ridges between to be cut away by hand and removed by side-filling. The machine can also work along a face, but has not then such scope as in a gullet.

Excavation of docks.

A steam-digger as here described is made of steel and iron, except the digging-arm, which may be made of wood or iron. Although strength and rigidity in the digging-arm and in the gear which propels it are essential, some play or elasticity is necessary to

prevent fracture when boulders or other obstructions are encountered. The engine is generally of about 10-horse power; the weight of the machine (exclusive of fuel and water) ranges from 30 to 35 tons, and the cost from £1,200 to £1,400.

Cost, power, and weight of steam-navvy.

Machine and manual digging compared.

The expediency of adopting excavating machines of the kind described in the preceding pages depends principally on the alternative cost of manual labour in the locality and the extent and nature of the work to be performed. When fully employed it has been proved by experiment that the steam-navvy will excavate at a saving of 1d. to 2d. per cubic yard as compared with manual labour. In the cost of the machine-process, interest on the purchase cost of the apparatus has of course to be reckoned, as well as the expense of repairs, deterioration, fuel, and the wages of the attendants; but accessories which are common both to machine and hand labour, such as the laying of the rail tracks and sidings, and the haulage of the full and empty wagons, may be excluded in comparing one with the other.

Expenses

Nature of the ground.

Too hard to cut.

Too soft to bear the machine.

The nature of the ground is of course a point of importance, for while sand, clay, alluvial soil, or gravel, and even chalk is mastered by the machine, hard gravel, large or numerous boulders, or any stratum that depends on the pick or on blasting, forbids the use of the machine; while on the other hand, if the ground be very soft, the maintenance of a track which will bear the weight of the machine may be so expensive as to be prohibitory. The desired depth of the cutting has also to be considered. If it is within the range of the machine at one or even at successive operations, it is much more profitably conducted than if a few feet in depth had afterwards to be dug out by hand. Some engineers object to the steam-diggers and other machine excavators because they disturb the ground more than hand-digging, and because also the large masses of spoil they remove are not so well suited for making solid embankments as is earth dug out in small spadefuls by hand. On the other hand, the contractor looks only to the cost of the work, and is sometimes also inclined to use the machines even when little or no saving is apparent, because of the check they afford on the demands of the men.

Machine-dug soil not solid for embankment.

Machine a useful check on men.

Favourable occasions for machine-digging.

Machine excavators compare most favourably where the work to be done is of considerable extent, where workmen for hand-digging are scarce or expensive, where skilled workmen for managing and repairing the machine are easily obtained, and where energetic con-

tractors with sufficient capital have the control. Such a combination of circumstances are likely to occur in the United States more often than in England, and the steam-diggers were therefore first introduced there, but in England also opportunities for its profitable use have occurred both on railway works and docks. But in countries where there is abundance of cheap labour, as in India or China, but where skilled workmen are expensive and repairs or renewals are difficult of execution, these conditions tell greatly against the machine. But in estimating the cost of manual labour, the rates of wages should not alone be reckoned, but the cost as measured by results. Climate and its effect on workmen have also to be considered. Thus, there are countries where, though labour may be cheap and abundant, the climate is so enervating that the workmen take frequent holidays, and works are much delayed. It may become expedient, therefore, to adopt machine-processes to save time even at a greater expenditure of money.

Inexpedient where labour is cheap.

Effects of climate.

Saving in time.

Subaqueous excavation.

See also DREDGERS, *page 397.*

Pumping.

In the excavation of wells, mine-shafts, or pier-cylinders, so long as they are unobstructed by water, workmen can descend and dig out the spoil, which can then be hoisted in the ordinary way by buckets; and even if water be met with, it may often be kept back by pumping, so that the workmen can still descend; this, for instance, being generally possible in a clay stratum. But if the excavation has to proceed under water, mechanical means of some kind have to be adopted, and in the course of time and to meet very different circumstances, a great variety of methods have been tried. If the ground be loose sand or mud, it may be pumped up, or a sand-pump may be worked by compressed air; and in the case of light clay or loam it may, if better methods are not available, be so stirred or loosened from above as also to be lifted by pumps. But as excavation or cylinder-sinking has generally to be continued till a firm foundation is reached, pumping hardly ever suffices alone. By means of divers, work can be carried on under water, and if the excavation be in cylinders or caissoons which can be closed in at the top and made air-tight, pneumatic methods are available, but only at depths less than 100 ft.

See DIVERS, *page 407.*

See page 409.

Mechanical digging indispensable.

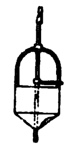
While therefore, in moderate depths, mechanical excavators which will act under water may, although generally the cheapest, be only one of various methods available, they become at the above depths indispensable. Sometimes the excavation of the soil and the

bringing it to the surface are performed by separate apparatus. Thus, as stated above, the strata may be so loosened as to be pumped up. This principle has been elaborated in the sinking of pier-cylinders by the use of revolving ploughs or cutters worked from above to dig out the soil, which, when loosened, flows upwards through a syphon, a sufficient current of water being maintained in the syphon by pumping water into the cylinder so that the water level is always above that of the water outside. This method, which has been adopted in deep river-foundations, is costly because of the engines, pumps, barges, and other apparatus required.

Revolving cutters.

Spoil raised by syphon.

Self-acting buckets or scoops, for vertical action only, are made in a variety of ways, and great discrimination is needed to choose what is best suited to particular cases as they arise. Small circular boring-buckets or "misers" are useful sometimes in well-sinking, and can be employed for excavating in cylinders also. The most useful size is about 12 in.; they are made even up to 4 ft., but these are cumbrous in action and are not suitable for excavating considerable quantities.



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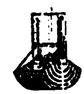
Misers.

Buckets or scoops suspended from a chain are, if effectual, the most convenient kind, but as neither a thrusting nor a screwing motion can be transmitted through a chain, it is necessary that the scoop or bucket shall have a self-contained action. The scoops that have proved effectual, though of various kinds, are generally made of a segmental form hinged, so that when descending they are open and ready to grasp the spoil, and when the hoisting commences they close and hold fast what has been grasped. In soft sand or mud the mere weight of the apparatus causes it to sink so far as to fill, and many of the scoops which have been used might be better described as self-filling machines than as excavators, and in this respect they may be used with advantage for hoisting grain out of barges, and, if open forks or grids be substituted for the complete bucket, will serve for hoisting coals or straw.



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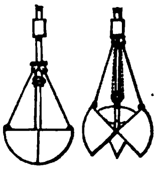
Self-acting scoop.

To obtain a cutting action, it is endeavoured in the pivoting or hingeing of the scoops to give such a direction to the cutting edge that when the hoisting chain, by becoming taut, tends to pull the segments of the machine together, they cannot close without cutting downwards and grasping the soil. But generally, the tension of the hoisting chain has not been sufficient for this, and a second chain attached to the hinged parts has had to be pulled, or a blow from a falling weight given to the bucket to force it into the ground. By these means very effective work has been done in the excavation

Mode of working.



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See page 402.

of pier-cylinders inaccessible to other kinds of apparatus, and the improvements already (1880) accomplished render them available for dense clay and other hard strata. In some of the scoops, the closing by a separate chain has been much simplified and improved; while in others, the separate chain is unnecessary, unless a very tenacious clay or hard gravel is met with, the buckets being made to close and grasp the spoil by means of self-acting cranks and levers. But even these harder materials may be dealt with if the depth do not exceed 30 ft., as by an ingenious application of a hydraulic ram the scoop is thrust into the ground with sufficient force.

Boring-tools.

Boring-tools, which find their principal use in prospecting for minerals and in sinking artesian wells, are useful also to the engineer or contractor for proving the nature of the ground for foundations. The latter may sometimes be sufficiently ascertained by digging trial-pits, and such pits dug on the banks of a river will occasionally suffice even to prove the stratum likely to be met with in the river-bed itself. But water in the pits generally hinders the excavation in this way, and for any but moderate depths boring-tools become necessary. In the construction of bridge-piers, of whatever kind, it is important that the nature of the foundations should be investigated before the form, dimensions and depth of the piers can be determined. The firmness of the ground or the friction it would afford to piles screwed or driven down, may sometimes be sufficiently ascertained by driving iron-shod piles or iron bars into the ground and carefully recording the shape and size of such piles or rods, as well as the number and weight of blows by which they have been driven a certain depth. But information so obtained is inconclusive and more elaborate plans are generally necessary. A sample from the bottom of a trial-pit, when water hinders further excavation, or from the river-bed itself, may be obtained by a worm-auger of peculiar form screwed into the ground. The depth to which this plan is effectual depends on the cohesion of the soil. If of clay or gravel it may be used for 6 or 8 ft., but the sides of the hole often fall in, and a fair sample can only be obtained by first driving a tube and screwing down the worm-auger inside it.

For proving foundations.

See page 49.

For bridge-piers.

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For boring considerable depths, either in prospecting for minerals or in well-sinking, if the stratum to be pierced is approximately known, it may be possible to confine the choice of tools to those most suitable; but where the nature of the strata is uncertain, the

boring apparatus must vary in kind, so as to pierce any stratum that may be met with. For most kinds of ground, a boring-rod shaped like an auger (223) is screwed into the earth, but when rock has to be pierced, cutting-chisels or "drills" (224,225) are driven by percussion. A tripod or sheers is placed over the bore-hole, and, by means of a rope passed round a pulley, the rods can be lifted, a windlass being used for winding the rope; and when rock or stony ground is met with, the process of "jumping" the hole is performed by lifting and letting fall the rods, the weight and percussive force becoming very considerable as the depth increases.


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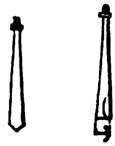
224 225

Chisel drills.

A usual method of commencing boring operations is to use first a worm-auger (226) for penetrating the hard crust and for loosening the earth below, and then to substitute an open or "clay" auger (223). A short length of pipe is sometimes driven into the hole at the commencement so as to prevent the surface-earth falling in. The turning is done by means of tillers or handles fixed on the top length of rod and worked by two men so long as the process is easy, and then, by lengthening the handles, by four or more men, or by cattle or steam-power. The rods are made in lengths of 10 or 20 ft., and a length is added as the tools descend. When the auger is full of earth or clay, it, with the rods above it, is raised by means of the sheers and windlass, and the augers emptied. In deep boring, as the depth increases, the uncoupling of numerous lengths of rod each time that the augers are lifted becomes tedious, but some of this labour may be saved by erecting light but lofty sheers above the bore-hole, so that lengths of 40 ft. may be lifted at once. For longer lengths a light framework may be erected, or a tripod of poles lashed together at the top. Or if the first part of the excavation has been by digging, the boring-rods may be worked from the bottom of the well or pit, and the rods may be uncoupled only in long lengths. Thus if the pit be 50 ft. deep, the rods need only be divided into similar lengths. When it is desired to examine the stratification of the ground more exactly than the ordinary auger allows, an auger of peculiar form is used in which the earth or clay passes up intact as a solid core. If rock or stones are met with, and it is necessary to cut through them, a chisel-ended tool is substituted for the auger and is "jumped" or driven against the rock by lifting the apparatus by the sheers and letting it fall, its own weight giving the necessary force. This plan becomes difficult at a great depth, as the rods vibrate and break the sides of the hole;


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Boring-rods in 10 or 20 ft. lengths.

See Figs. 224 & 225.

See also ROCK-DRILLS *and* DIAMOND-DRILLS.

the great weight requires considerable force to lift the rods at each blow, and tends to break the lower lengths. Boring-rods of this kind are partially turned at each blow so as to make the hole circular.

Shell-augers.

If the tool passes through the rock, recourse is again had to the auger, unless the ground has become wet or soft, when another tool, called the shell or pump-auger, which has a valve at its extreme end, is used, and this valve will retain silt or sand or anything too soft to pass up the ordinary auger. When boring through a running sand or other soft stratum, it is necessary to drive a pipe down the bore-hole to prevent the soil closing round and choking it. The pipe is passed down from the surface through the hard ground, and is then driven through the soft lower stratum, the pipe being cleared from time to time by a shell-auger. If hard stratum be again encountered, it is necessary to recommence with a tool of smaller diameter that will pass through the pipe. Hence, when deep borings are anticipated, it is important to commence with a large tool, as it may be necessary to reduce the diameter three or four times in a depth of several hundred feet.

Boring through pipes.

Deep boring at reduced diameter.

Grappling tools.

The tools above described are made of various sizes and shapes to meet the different occasions that arise, but besides the actual boring-tools and rods there are numerous secondary tools that become necessary. Thus there are grappling tools of various kinds and shapes for seizing rods or pipes that become disconnected in the bore-hole or stones that impede the augers; pincers, clamps, hooks and tubes. All these must be made of good tough iron or steel to withstand the rough usage and the oft-repeated strains that are unavoidable in boring operations.

Cost of boring-tools.

For testing ground down to 30 ft., the necessary tools can be purchased for about £15, but the expense increases with the depth of bore-hole, so that the tools cost about £100 for a bore of 300 ft. The deeper the hole, the greater the variety of strata likely to be met with, and therefore a corresponding number of tools must be provided. Moreover, if deep boring is anticipated, the hole must be made of large dimensions at the top, larger and more expensive augers and chisel-drills becoming necessary. The rods are square bars of iron or steel with screwed socket-joints, and they are generally made in lengths of 10 ft. or 20 ft., and they must be strong in proportion to the depth of hole. Thus, 1-in. rods, costing about 23s. per 10-ft. length, are usually strong enough for holes 200 ft. deep; for holes down to 400 ft. 1¼ in. rods, costing about 27s. per 10-ft. length, are

Cost of rods.

needed; while between 400 and 700 ft. 1½ in. rods, costing about 36s. per 10 ft. become necessary, and so on. For deep borings, or where rapid work is desired, a steam-engine is a necessary adjunct, though horse or cattle power may be substituted. Staging, sheds and various other accessories have also to be provided, often at considerable expense.

Steam-power and accessories.

Choice of tools, how determined.

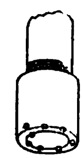
A proper choice of boring-tools depends upon a full knowledge of the circumstances; and therefore the purpose, the probable strata, the anticipated depth, the extent of the operations, and the diameter wanted at the bottom of the hole should be fully described to those concerned. The conditions under which boring operations are carried on are so varied and the accidents that occur so peculiar that experienced workmen are necessary for any but the simplest cases.

Diamond rock-drill.

See ROCK-DRILL, *page 391.*

The *Diamond Rock-drill* is used for sinking artesian or other wells, and for prospecting after minerals, and for hardly any other purpose; though occasionally it has been used for boring holes for explosives instead of the percussion rock-drill. For example it has been used for the latter purpose in subaqueous rock-boring through water about 14 ft. deep. Steel tools can pierce rock only by a succession of chisel blows; and as power rock-drills, which strike rapidly, are limited to a depth of about thirty feet, drilling through rock for greater depths is tedious and expensive. The piercing of rock by revolving drills is obviously a desirable plan, but steel having proved quite inadequate for the purpose, the "jumping" of holes by chisel-drills was the only available plan till the invention of the diamond-drill, which will penetrate the hardest rock. Indeed, it will work more easily in a hard granite or hard siliceous sandstone than in softer rocks. A hollow tube is used as the revolving spindle, and to the lower end of the tube is attached a ring or disc of larger diameter, known as the "crown," the face of which is studded with carbons or black diamonds, which, when the crown revolves, cut or wear away an annular space into the rock. The solid core of rock passes into the tube as the drill descends, and by a simple arrangement the core can be cut from time to time, and brought to the surface in lengths of from 1 to 15 feet. While the drill revolves, a stream of water is forced down the tube at considerable pressure, for the double purpose of counteracting the friction heat of the cutting-faces, and of bringing up in the annular space outside the tube the powdered rock which the drill has cut

Revolving and jumping drills.



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Cutting crown.

Mode of working.

away. Taking into account the expenses of repairing steel percussion drills, the diamond-drill will do the same work as cheaply and at a greater rate of speed.

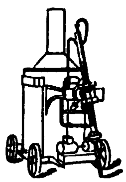
Diameter of drill-hole.

The diameter of the drill-hole depends on somewhat the same circumstances as in other kinds of boring, that is to say, on the diminutions that must occur from time to time during the descent. If there be hard strata throughout, the diameter need not be much diminished; for instance, a hole need only be 6 in. diameter at the top in order to be 3 in. diameter 500 feet below, this allowing for a core of about 1¼ diameter. It is usual, especially when passing through soft stratum, to line the bore-hole with tubes, and the allowance has to be made for these in determining the diameter of the hole. For prospecting, the smallest diameter that will work to the desired depth is all that is necessary, as a core of 1 inch diameter will tell the stratification almost as well as a larger one. But for well-sinking, where a tube for permanent service has to be inserted, diameters of from 12 in. to 24 in. become necessary. A solid core, 20 in. diameter, of the hardest stone can be brought up from a depth of 1,000 feet, and drilling can be carried on at a reduced diameter for more than 2,000 feet. The rate of progress will range from 2 ft. to 3 ft. per hour for depths down to 200 ft., diminishing 1 ft. per hour at 1,000 ft.

Bore-hole lined with tubes.

Solid core of rock obtained.

Deep drilling.



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Portable machine for prospecting.

A complete apparatus suitable for mine-prospecting, consisting of small steam-machine and boiler, drilling-crown and diamonds, with drilling-rods sufficient for drilling 200 feet, with a core at the finish 1⅛ diameter, costs from £1,200 to £1,500, including 100 ft. of lining tubes and all necessary accessories. A small apparatus of this kind can be mounted on wheels and taken quickly to the desired place, set to work, and as quickly removed. It is suitable for depths down to 1,000 feet. The drill works most easily downwards, but can, if need be, work at any angle. But although a machine of this kind is portable and convenient for prospecting, it is better in the case of large holes or deep boring to have a detached boiler, and, if the situation allow it, lifting apparatus above the bore-hole for raising the rods. A derrick or sheers may be used for this purpose, but it is better to have a lofty framework, or staging of timber, or angle-iron, which can be so made in lengths as to be packed in bundles for transport.

Cost of drilling.

The cost of rock-boring depends on so great a variety of circumstances that no fixed rates can be stated, but where coal is

obtainable at 30s. per ton, a prospecting machine as just described can be worked at a cost of from £3 to £4 per day, and with such a rate of expenditure the total cost will range from 5s. to 12s. per foot. When large holes are bored, as for wells, tubular rods of from 6 in. to 18 in. (generally made of weldless drawn steel) are used; the cost of the apparatus rapidly increases, and for depths of from 1,000 to 2,000 ft., the outlay often exceeds £4,000, and the cost of boring 20s. to 50s. per foot. The cost of lining-tubes will also range from 5s. to 40s. per foot, the cost increasing with the depth.

Large holes for artesian wells.

Lining-tubes.

See page 237.

Diamond-drills as just described will pierce the hardest known rocks, but sometimes it is expedient to use them in combination with ordinary boring-tools. Thus ordinary tools may be used through soft upper strata or chalk; and if loose flints are encountered, a jumping-drill will break them easier than the diamond-drill, which is apt to loosen and turn them round rather than cut them. As in other kinds of boring, various contingencies have to be provided for, and none but men accustomed to the incidents of boring can overcome the difficulties that may arise.

Ordinary tools used in conjunction.

Difficulties.

The diamonds found most suitable range from 2 to 6 carats (according to the size of crown and bore-hole) and cost generally from 20s. to 30s. per carat, but occasionally there are wide fluctuations in price. About 12 diamonds are required in a crown of small diameter and about 30 in the largest. Great care is required to set them firmly and in proper sequence, but if this be done, they last a long time, and if occasionally re-set so as to obtain a new cutting-edge, they will sometimes drill more than 500 ft.

Weight and cost of diamonds.

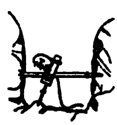
Setting and re-setting.

A supply of water is essential to drilling by diamonds, but when water is scarce, it can be stored in pits and re-used. Although the drilling to a certain depth may be anticipated with certainty, the diameter of the hole at the finish can seldom be predicted. Bore-holes can be enlarged by rimering, the diamonds being specially arranged for the purpose. But this costs as much as drilling a new hole.

Water supply.

Holes enlarged.

Percussion Rock-drills are used in sinking shafts and driving galleries in mining and tunnelling, for boring the holes in which the explosives are placed. Drilling by hand, which was the only plan available till machine rock-drills were invented, is slow and laborious, and quite inadequate for large or speedy operations. The actual drilling-bit, or boring-tool of the machine resembles the hand-drill in being



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Rock-drills.

driven against the rock by a succession of blows, and in the partial turning of the bit between each blow, but the bits or boring-tools themselves are generally stronger, being made of various shapes from steel rolled for the purpose. While a hand-drill is limited to 8 or 10 comparatively feeble blows per minute, a machine-drill gives from 300 to 1,200 blows per minute, and each with great force according to the diameter of the cylinder and pressure available.

Description. A machine-drill forms a complete steam-engine or compressed-air engine. There is a cylinder with piston, and to the piston-rod the drill is attached, so as to give a direct blow on the rock, a fresh length or piece of drill-bar being inserted, as with well-sinking or boring rods, as the hole advances. The blow is struck as by a chisel, and between each blow the drill turns partially, so as to render the cutting edges effective and to maintain a round hole, the drill being made to advance by a forward movement of the cylinder, in some machines automatic (though this feature is not, in most cases, of much importance); and it is in these points, as well as in the kind of slide-valves or other mode of controlling the steam or compressed air, that the machines of different inventors differ.

Motive power. Steam and compressed air are the motive powers generally employed for rock-drills, the elastic force being well suited to the sharp percussion required. Water has been used as a motive power, but the occasions when it can be obtained in sufficient quantity and force at the right place, without its exhaust or "tail" being in the way, are so rare that it hardly needs consideration. **Steam.** The direct use of steam is the cheapest, as there is necessarily loss of power when a steam-engine is applied to the intermediate purpose of compressing air, and there is again a loss when the compressed air gives out its force in the drill. *See page 87.* Moreover, while only a steam-boiler is wanted in the one case, an engine and air-compressor are wanted in the other. For these reasons, steam is preferred in those cases, such as open quarries, where its use is practicable and convenient. But rock-drilling has in the majority of cases to be done in mines and tunnels so far from the open air, or in such confined spaces, that a boiler **Inconveniences of steam.** for generating steam becomes impossible, and even if steam be brought in pipes from the outside it is oppressive or unendurable. **Compressed air.** The modern system of using as power compressed air, brought in *See page 89.* pipes from a compressor at a distance, has therefore proved of great advantage, and is indeed more associated with rock-drilling than with any other operation. The manufacture of air-compressors for

the purpose has become a specialty of trade. Even in open work, compressed air is frequently employed where the apparatus has to be provided for tunnel work.

Compression by water-power.

Where cheap water-power is available for turbines or wheels for compressing the air, the loss in transmutation may be of little consequence, and rock-drilling is performed under the most favourable conditions, because, apart from the cost, air is preferable to steam. In regard to the transmission of steam from the boiler to the drill, there is always loss by condensation, the precautions for retaining the heat, which are usual and feasible in permanent situations, being inconvenient in temporary and movable apparatus; and the limit of distance is less than with air, which can, if need be, be conveyed for several miles in pipes with little loss. Moreover, if steam be used, the machine and pipes become inconveniently hot, and the exhaust-steam is an annoyance. Compressed air is free from these objections and has, as already described, the distinct advantage of cooling and ventilating the place where it is discharged, a circumstance of great value in mines and tunnels, especially where the air has been fouled by the explosion of gunpowder or dynamite.

See page 74.

See page 90.

See page 91.

The leading dimension which determines the power and cost of the machine is the diameter of the cylinder; and as the size, strength, and weight of the parts are also governed by this, the exigencies of portability and space, which render a moderate size and weight necessary, of course limit the power of the machine. The smallest machines are those made with cylinders of about 2 in. diameter, but these are used only for such purposes as splitting blocks and drilling plug-holes. The more usual sizes of machines range from those having cylinders $2\frac{1}{2}$ in. diameter, with a piston-stroke of 3 to 5 in., and with a 16-in. length of feed, up to those with cylinders 4 in. diameter, 7-in. stroke, and 3-ft. length of feed. Machines of 5 in. and even $5\frac{1}{4}$ in. diameter have been made and used sometimes for prospecting on exposed reefs, or for deep holes (30 ft. to 40 ft.) where the weight of the rods requires extra power, but they are unnecessary even for the most extensive tunnelling work.

Usual sizes of rock-drills.

Diameter of piston.

Choice of machines.

The kind and number of machines necessary for any particular case depend mainly on the purpose and extent of the operations. Single small machines, though apparently effectual for a depth of two or three feet, are quite insufficient for speedy work either in mining or tunnelling, and if, as often happens with inferior machines, they get out of order and cause delay there is no advantage over hand

jumping-drills. To bore rapidly and continuously without breaking and the facility of ready adjustment are the chief recommendations of a boring-machine. The action of a machine rock-drill is so severe as

Machines liable to damage.

to suggest that it must knock itself to pieces, or irretrievably damage some of its parts; and too often this is the result, only to be postponed by slow working at moderate pressure. A strong, well-made machine, which will work effectually at moderate speed and pressure if the available power be small or if applied to easy work, and yet which will, without damage, work at high pressure and speed if opportunities offer, is the one which is most remunerative in time

Range of pressure. *See page 94.*

and money. A machine-drill will work with a pressure of 20 lbs. per square in., but a pressure of 50 or 60 lbs. is best if the rock be hard and the machine well made. Generally it will be found that additional capital outlay to obtain the best apparatus is amply

Ample power required.

repaid in a few weeks of working. Ample motive power should be provided, for although there may be periods of rest, during which steam may be generated, a machine when working to the best advantage demands a full and continuous supply. Even for small machines it is seldom advantageous to have, if worked directly by

Boiler and engine.

the steam, a boiler of less than 6-horse power, and this will suffice for two small machines. When the drill is worked by compressed air an engine of less than 10-horse power is seldom satisfactory. For each rock-drill employed, an additional expenditure of from £20 to £30 for air-tubing and drill-steel must be reckoned, but for tunnel work, when compressed air has to be brought a long distance, the

Pipes. *See pages 94 & 227.*

cost of pipes is of course much larger. The proportionate power required for hard and soft rock occasionally varies with the depth of the hole, because there are some kinds of rock, such as sandstone, of which the chips and dust so choke the hole that, where long drills are needed, the aggregate friction more than equals the resistance of hard granite, although in the latter case the point and edges

Limits of depth in boring.

of the bit are blunted more. The limit of depth depends primarily on the power of the piston to lift the drill-rods in a vertical hole or to overcome the friction on the lower side in a horizontal hole. The maximum depth to which a machine rock-drill is effective is about 30 ft., but the great majority of drill-holes for explosives range from 3 to 6 ft. The depth of the hole not only increases the resistance, but diminishes the effective diameter of the hole or explosion-chamber, because, to enable the drills to clear themselves, the

Tapering holes.

diameter of the hole at each successive length becomes less, the taper

of a hole ranging from $\frac{1}{80}$ in. to $\frac{1}{10}$ in. per foot. And if the hole be at an upward angle, the weight of long drill-rods diminishes the effect on the point, but, on the other hand, assists in clearing the drill in the backward stroke.

As the ultimate purpose of a drill-hole is the fracture of the rock, the effective use of a machine depends not only on its capacity, but on the skill with which the holes, in their direction, diameter, and depth are adapted to the kind and stratification of the rock, so that the explosive will split it most effectually. In this respect, the choice of method depends upon whether the mere removal of the rock is the object in view or whether the material itself is of value; and, as in the case of slate, marble, or building-stone, where pieces of certain shape and size are required, the holing and breaking must do the minimum of injury to the pieces. The diameters of ordinary blast-holes range from $\frac{3}{4}$ in. to 2 in., but they are seldom less than 1 in., except for plug-holes. The diameter depends, to a considerable extent, on the depth of the hole; first, because, owing to the clearance space for the successive lengths of drill, the deeper the hole, the larger it must be at the outer end to allow of a taper towards the drill point; and secondly, because the deeper the hole, the larger is generally the mass to be moved, the greater the effort required, and therefore the larger the explosion-chamber. It is often advantageous to explode first a small cartridge, which clears the hole and makes a chamber for the effective explosion.

Use of explosives.

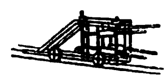
In quarrying.
See also page 396.

Diameter of hole.

Explosion-chamber.

It is impossible to state exactly the depth of hole which a rock-drill will make in a given time, as the variety of circumstances to be taken into account is obviously very great. Thus, while a good machine will drill as much as 6 in. per minute in hard rock, the adjustment of the machine as well as the withdrawal and renewal of the boring-bits occupies time so that, even with such a machine, from 70 to 100 feet per day of ten hours, if maintained regularly with the same machine, may be considered satisfactory. The efficiency of a machine depends also on the kind and suitability of the accessories. For ordinary mining or prospecting, two 3-in. machines will generally suffice at each place of working, but for large tunnelling operations four or six 4-in. machines on one carriage become necessary if the full advantage of the process is to be obtained. The most rapid work in large tunnels can be carried on in a heading 7 ft. by 7 ft. A simple tripod stand is sufficient only for the easiest cases, and it is almost always advantageous to have stands or carriages which allow of easy

Speed of drilling.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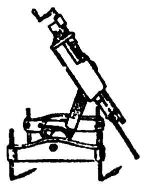
adjustment in every direction, and yet which will remain steady under very severe work.

Cost of rock-drills.



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A rock-drill with 3-in. cylinder costs about £100, and to this must be added the cost of the stand. A tripod or stand of the simplest kind costs from £12 to £20, and weighs from 100 to 150 lbs.; but it is generally expedient to have a stand better adapted to various positions and steady under severe work; such stands costing from £30 to £60, and weighing from 100 to 250 lbs. A 10-horse power steam-engine and air-compressor sufficient for two, or even for four machines, if not all working at once, will cost about £400.

Cost of large apparatus.

For rock-drilling on a large scale much more elaborate machinery is required. A carriage with air-container, and having six rock-drills attached to it, so that it can advance on a line of rails against a tunnel face, costs from £1,000 to £1,200, and the air-compressing machinery and the numerous accessories would cost from £2,000 upwards. A complete equipment for the largest tunnelling operations would cost about £5,000 if the full advantage of the machine process is to be obtained.

Steel for drills. *See page 155.*

Steel of the best kind for the bits, hard for cutting and yet easily welded, is essential to the profitable working of a machine-drill. Such steel costs from £60 to £70 per ton.

Rock-drilling under water.

Rock-drilling is sometimes carried on under water. A machine fixed on a staging or boat can work through water as deep as 10 ft., but beyond this, the percussion of so great a length of drill without guides tends to break it, and it becomes necessary to place the drill near the place where it works. Rock-drills may be worked by a diver in helmet and dress, or from a diving-bell, and while one tube supplies the compressed air to the machine, another tube brings the exhaust-air to the surface, so as to avoid the back pressure on the piston if discharged into the bell. When the bell or caissoon is in water not less than 50 feet deep, the machine-drill may be worked by the compressed air in the bell.

By divers. *See pages 407-11.*

Quarrying by rock-drills.

The rock-drill has been used almost exclusively as a preliminary and accessory to explosion, which however so breaks the rock or stone as to render the pieces of little value. But improvements have already (1880) been made by which the rock-drill, suitably mounted and controlled, may be traversed in a direct or curved line, so as to cut a chase or channel in the rock, and by mounting several drills on one carriage, several channels can be cut at the same time. By this means a curved or angular block may be cut on every side and

Cutting of channels or grooves.

removed by the further aid of dynamite. Rock-drills working in this way can cut a given amount of rock more rapidly than by holing, for in the latter case the successive blows in the same holes makes a resisting pad of *débris* in front of the drill, while in traversing, the drill always strikes on the edge of the preceding blow and breaks away the rock more easily.

To allow a proper choice of apparatus for rock-drilling, some or all of the following information is required according to the nature of the case. **Choice of rock-drill, how determined.**

1. The general purpose and extent of the operation, whether in a quarry, tunnel or mine; and some indication of the extent or rate of progress required. **Purpose.**

2. The kind of rock or stone to be drilled, its formation, and whether it is immediately accessible or covered with an upper stratum of other materials. If so covered, it is usual to dig a hole or sink a shaft so that the machine may be placed immediately on the rock. A drawing showing the mine-shafts, a section of the rock, and the direction of the holes is useful. **Kind of rock.**

3. If for quarry work, the diameter and depth of holes required.

4. Whether steam or compressed air is to be used; whether boilers, engines, or compressors are required; or, if power is already provided, its kind and extent. **Steam or air power.**

In conclusion, it may be said that no kind of rock-drill and carriage that have yet (1880) been invented is suitable for all circumstances, and that, to obtain the maximum effect, the whole apparatus must be adapted to the particular purpose in view. The importance of affording a full knowledge of the circumstances of the case to those concerned in the choice or manufacture of the drill is therefore evident. *See page 48.*

Dredgers (*dragues*) are made of various kinds, shapes and sizes, but though certain novel systems of excavation have been introduced, the characteristic feature, which is associated with the name, is the ladder or rigid frame which is suspended from a floating vessel, and upon which works the endless chain of buckets which scoop out the ground as they pass round the bottom of the ladder, and deliver it as they pass round the top. The ladder is so hinged at its upper end that it may be raised or lowered to any angle, so as to bring the lowest bucket in contact with the ground at any depth within the range or capacity of the apparatus. **Dredgers.** **Mode of working.**

Design, how determined.

See page 404.

The following points are those which determine the design of a dredger, and they are so numerous and the combinations so varied, that it is seldom that a dredger which has been made for one place and set of circumstances is appropriate for another.

Depth of excavation.

1. The quantity of material and the depth of excavation are the two main factors which form the basis of a design. A deep ladder needs a strong framing and boat to support it, and powerful machinery to work it, and the weight and cost of the apparatus increase accordingly. If the depth be considerable, of course the expenditure of force may be moderated by having small buckets, which bring up only a small quantity of spoil. In dredging a channel in tidal waters, the ladder must be long enough for the range of tide. Thus, if a channel 20 ft. deep at low water is required and there is a 10 ft. range of tide, the ladder to be always effective must be long enough to dredge at 30 ft.

Range of tide.

Nature of the ground.

2. The kind of material which has to be excavated. For mud or silt or loose sand the operation is little else but lifting (the friction of the machine, which is considerable, having also to be overcome); while for hard sand, clay, or gravel the buckets as well as the machinery must be strong enough and have force enough to cut into the ground.

3. The nature of the operation and the direction in which the work is to be carried on. Where a considerable area has to be excavated, or where there is a wide range of water in which the dredger may float, it may be immaterial from what part of the boat the buckets work, as the boat can move from place to place as the excavation proceeds, but if a channel has to be dredged between shoals or close up to a shore or quay-wall, the dredger-ladder must be placed accordingly. Thus it can be placed in the centre of the boat, or two ladders, one on each side, may be used, or, the ladder may be made to project from either end. Thus, a dredger-boat, while floating may be arranged to cut away a shallow by the shore or even the shore itself above or below water. But in deciding on the position of the dredging-ladder the mode and direction of delivery must be considered.

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Delivery of the spoil.

4. The delivery of the excavated spoil is usually into barges at the side of the dredgers, the full buckets as they turn over at the top of the ladder emptying into an inclined shoot, which discharges into the barge. If the ladder works in the centre of the boat, there may be shoots to each side, and, by a simple arrangement, the spoil may be

directed to the right or left hand to fill a barge on either side. Where the excavated material is of no value, and is merely dredged to deepen the channel, it is usual to discharge it into deep water in some place where it will not be inconvenient, or to utilize it for raising or reclaiming land by depositing it on shoals. For discharging the spoil into deep water what are known as hopper-barges are generally used for conveying the spoil, a false bottom or hopper allowing it to be discharged readily at the desired place.

Deposited in deep water.

Or on to shore.

Hopper-barges.

See page 401.

A powerful dredging-machine will keep employed numerous barges, and if the distance for transporting the spoil be considerable, the barges may with advantage be propelled by steam, so as to bring them back to the dredger as soon as possible. Sometimes, however, the spoil is carried away in the dredger-boat itself, this plan having been adopted for instance in tidal waters when the dredger could only work for a few hours each day, and when therefore its steam-engine could be utilised for propelling the boat, such hopper-dredgers being arranged for discharging through a hopper or false bottom in the usual way, and a hopper-dredger can fill not only its own hold, but a barge also, which it can tow. This plan saves considerable expense in barges, tug-steamers, and labour, but against it has to be set the time which the dredger-boat is withdrawn from its primary duty. Such an arrangement does not add to the cost of the dredger so much as would purchase steam-barges, but the saving in wages or other expenditure must be carefully investigated before the outlay is justified. There is the disadvantage in using a dredger-boat in this way, that when it is brought back to work, time is expended in adjusting and mooring it to the face which it was operating against. A decision can only be arrived at in each case by duly estimating the distance, the times of working, the wages of the workmen, and other circumstances.

Steam-barges.

Hopper-dredgers.

Compared with separate barges.

In cases where the dredged material is of value, as in the case of river-sand for mixing mortar, or clay for bricks or Portland cement, it may have to be carried ashore; and in such cases, it may be either removed by the spade and wheelbarrow, or by cranes and self-filling scoops, or by a land or floating dredger with buckets which discharge into wagons on the shore. The cost of conveying and depositing the spoil is generally as much as or more than that of dredging, and numerous plans have been tried to reduce the expense. Where mud which can be kept in a semi-liquid condition has to be dealt with, it may be discharged by pneumatic pressure, specially contrived

Dredged spoil sometimes valuable.

Delivery on shore.

barges with air-tight chambers and steam-engines being employed. As by this means the spoil can be forced 500 ft. or more through a tube, the expenditure in fuel and wages for the steam-engine is in most cases less than that in wages for other methods. The plan of forcing through tubes may be adopted with advantage in reclaiming land in water too shallow for the barges to approach. In narrow rivers or canals, the excavated spoil is often discharged on to the shore as it is brought up in the buckets, by long shoots or pipes from the dredger-boat, this plan being, for instance, often adopted in the dredging of irrigating-canals, and it was adopted in the construction of the Suez Canal, the channel being excavated and the banks formed by the one operation. Tubes as long as 100 ft. can be suspended from derricks or masts erected for the purpose; and where, owing to the level of the shore, an incline sufficient for gravitation cannot be obtained, the flow of the spoil can be assisted by pumps. Sometimes, instead of an overhead shoot, a syphon-pipe conveys the spoil under water on to the shore; in this case, as with the overhead shoot, the movement of the spoil being assisted by a copious flow of water supplied from a centrifugal pump.

Spoil forced through tubes.

Syphons.

Dredger-boats as above described are costly, and the service is so severe that expensive repairs and annoying delays can be avoided only by having every part of the best and strongest kind. The ladder is formed of wrought-iron, and the links which hold the buckets are either forged from high-quality iron, or of iron bushed with steel, or are made as steel castings. The shape, size, and material of the buckets depend on the nature of the material to be excavated, but even for sand or mud it is usual to make the cutting lips of steel. To utilise a dredger-boat to the utmost, the steam-engine must be powerful and the connecting gear very strong.

Dredgers are costly.

Must be strong.

And powerful.

Dredger-boats are made at all prices between £3,000 and £25,000. A boat 90 ft. long and 15 ft. wide, drawing 1½ ft. of water, with 8-horse power engine and machinery for dredging from the bottom of a canal 6 ft. deep, would cost about £3,000. A boat 80 ft. long and 20 ft. wide, drawing 4 ft. of water, with 25-horse power engines for dredging 70 cubic yards per hour from the bottom of a harbour or river channel 25 ft. deep, would cost about £4,000. A boat 120 ft. long, 24 ft. wide, drawing 6 ft. of water, with engines of 40 nominal horse-power, and capable of dredging from a depth of 25 ft. from 150 to 200 cubic yards of mud or sand per hour, would cost about £9,000. A dredger-boat 120 ft. long by 33 ft. wide,

Cost of dredgers.

Ranges from £3,000 to £25,000.

Cost of barges.

drawing 5 ft. of water, with engines of 50-horse power, capable of dredging 300 cubic yards per hour from a depth of 40 ft., would cost from £14,000 to £16,000. A dredger-boat 160 ft. long, 30 ft. wide, 10 ft. deep, with 70-horse power engine, capable of dredging 400 to 500 yards per hour from any depth between 7 ft. and 32 ft., with propelling engines for a speed of 5 miles per hour, would cost about £24,000. A hopper-dredger, capable of dredging 300 cubic yards per hour, and with carrying capacity for 1,000 tons, would cost about £25,000. Hopper-barges, equipped with propelling engines and other appurtenances, and capable of carrying 300 to 500 tons of spoil, cost from £5,000 to £9,000. The exact cost of a dredger-boat or barge depends not only on the current value of iron and other materials at a particular time, but on the kind and number of accessories and duplicate parts required.

Cost of barges.

Accessories and duplicate parts.

See pages 41, 180, & 404.

Dredger-boats are so costly, and the expense and risk of navigating them across the sea are so great, that in foreign countries it is sometimes sought to economize by importing only the machinery, and to utilize an ordinary vessel for holding it. But this plan cannot be adopted with advantage, as the size, arrangement, and construction of the boat must be specially suited to the purpose in view. It is possible sometimes to build a suitable vessel in a place where the machinery itself cannot be made, but as iron boats are generally preferred, it is seldom that they can be built except in places where the machinery also can be made. Sometimes, however, the dredger-boats are imported in pieces, and put together in the place where they are to be used, and in other cases the wood-work and internal fittings are made in the importing country. The cost of navigating a dredger-boat across the ocean is sometimes very great (from £1,000 to £3,000 has often to be paid, including insurance), as compared with the cost of freight when carried in pieces as cargo; but against any saving so effected, has to be set the cost and risk of putting the machinery together in a foreign country. Hopper-dredgers allow a saving in this respect, as they are large and strong and cost less for navigation than a dredger-boat and separate barges.

Ordinary vessels as dredgers.

See page 402.

Dredgers sent in pieces.

Or sent complete.

Cost of navigation.

See page 40.

Although the work of dredging has been greatly improved, and the cost reduced, there is always the disadvantage in the machines just described, that, owing to the friction of the bucket-links passing round the ladder, and the weight of the machinery to be moved, the effective work done as measured by the weight of spoil lifted to a certain height is only about one-third of the power employed. But

Friction of dredger machinery.

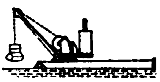
In proportion to results.

so cheap is the force which a steam-engine can give out when compared with manual labour, that even with these disadvantages, sand, mud, or clay can be excavated and lifted very cheaply; the cost, including interest on the outlay for the dredger, and all other expenses of dredging at a depth of 25 ft. below the water level, and delivering at a height of 10 ft. above the water, ranging from 3d. to 9d. per cubic yard. In the case of hard clay, gravel, or clay with large boulders, the cost ranges from 7d. to 20d. per yard. The cost of conveying and depositing the spoil depends on so many circumstances that limits as wide as for dredging are necessary. Probably 4d. to 20d. will include the great majority of cases. A cubic yard of spoil weighs approximately one ton.

Cost of dredging per yard of spoil.

See EXCAVATION, *page 379.*

Various plans have, however, been tried of subaqueous dredging by other and simpler means.



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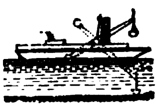
Scoops worked by steam-crane.

See page 385.

A steam-crane, fixed in a floating barge, may be used for lifting the self-acting scoops already described, and an apparatus of this sort (usually known in America as a dipper-dredger), though perhaps not so suited as an ordinary ladder-dredger for long and continuous service, will do effective work, with a much less capital outlay. The buckets may be made to hold any quantity between 10 and 40 cwt., and will dredge from a depth of 20 ft. from 200 to 700 tons of mud, or from 100 to 400 tons of clay per day, according to the size of scoop. A complete equipment of steam-crane with a radius of 18 ft., with scoops, chains, and other necessary accessories except the barges, costs from £500 to £1,000, according to size. By this plan excavation may be carried on in corners and narrow places inaccessible to an ordinary dredger. Sometimes the crane is fixed upon a wharf or jetty and discharges either into trucks on shore or into barges.



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Self-acting scoops.

See page 386.

Worked by rocking-beam.

This application of self-acting scoops to dredging has been attempted on a larger scale than that just described, and in vessels specially built for the purpose. The bucket is suspended from a rocking-beam so well balanced as to require in order to work it only a small proportion of the power necessary for the ladder buckets and other machinery of an ordinary dredger. The rocking-beam is worked either by a steam-engine or by hydraulic power, and is so arranged that it can dredge at any level from 6 ft. above the water surface to 30 ft. below, as may be required. For mud or sand no power need be applied to the scoops except that of lifting, but for hard clay or ballast a hydraulic ram attached to the end

of the beam gives the necessary thrusting motion. Dredger-boats completely equipped with apparatus of this kind would cost only about two-thirds of an ordinary dredger-boat of similar capacity, and if they prove able to work continuously without difficulty or inordinate repairs, they will probably be widely adopted.

Excavation by water or air pressure.

All the dredgers which have been here described have some moving machinery by which the material is grasped and lifted in buckets, but for soft mud or sand it is endeavoured to bring up the spoil in pipes without any such moving mechanism. This plan can be carried out either by water or air pressure. In the former case it is endeavoured so to stir up or loosen the sand or mud that a chain-pump, centrifugal-pump, or other pump not liable to be choked, will raise the spoil in a semi-liquid state. A jet of high-pressure air or water directed to the desired place is the means generally employed for this purpose.

Pneumatic method.

See page 411.

By air-pumps.

See page 86.

There are various methods of applying air pressure. Thus, the soil may be forced upwards directly by the compressed air, either as presently described in the case of air caissons, or by means of a special apparatus of vacuum chambers and air-pumps, which maintain a vacuum in pipes pushed into the sand or soil to be excavated; a second pipe with compressed air or pressure-water scouring out the soil and assisting in forcing it up the vacuum pipe. The spoil can be propelled 500 ft. or more in the pipes if required. It will be seen that by this plan the spoil is really lifted up by pumping, the combination of vacuum on the one side to increase the effect of the air pressure on the other, being the peculiarity. By these plans of excavating by means of pipes and pumps, there are the advantages that much of the machinery and plant of an ordinary dredger-boat are avoided; and the pipes occupy so little space as to be applicable in cylinders or caissoons where there may be not room for moving buckets, and also in narrow spaces and corners in harbours or docks. But there is the disadvantage that in lifting the spoil in a liquid condition, it is generally necessary to lift with it an equal or even greater quantity of water, the weight of which, of course, has to be deducted from the effective service of the motive power.

Compared with ordinary dredger.

Choice of dredger, how determined.

In designing or selecting dredger plant for use in any particular case, the following are the leading points which have to be considered, and on which full information should be supplied to those concerned.

Purpose. 1. The purpose to be effected, whether the removal of a bar, the deepening or widening of a river channel, the removal of banks or shoals, or the clearing of a dock.

Space available. 2. The space available for the dredger, as in a wide or narrow river, harbour, or canal; and any particulars which may determine **Delivery of spoil.** the direction of delivering the spoil from the buckets, whether into barges alongside, or at the end of the dredger-boat, or on to the shore. The above particulars may be given with advantage on a **Soundings.** map, plan, or chart, on which also may be marked the soundings and the depth of excavation which is required.

Tide or current. 3. The lift of tide, or the range of flood level, and the strength of current.

Nature of ground. 4. The nature of the ground to be excavated, and if varying according to depth, a section as nearly as may be of the strata; and if boulders, sunken trees, or other obstructions are likely to occur, their probable kind.

5. The periods of working, whether permanent or occasional, at **Amount of spoil.** tidal or other intervals, and the amount of excavation required in a given time.

Depositing of spoil. 6. Particulars regarding the depositing of the spoil in barges, whether in deep or shallow water, or on shore; the distance from the place of excavation; the mode of conveying the spoil, and the time occupied in transit; and any circumstances which may help to deter- **Barges.** mine the kind of hopper-barges required, or the expediency of conveying the spoil in the dredger-boat itself.

Size of hull. 7. Whether living room is to be provided on board the dredger, and if so, for how many men, and the storage space required for fuel, water, and provisions.

Depth and width. 8. Particulars as to the length, width, and depth of water of any locks, dock-entrances, quays, or other spaces, which may affect the shape, dimensions, or draught of the boat.

Fuel and water. 9. The kind of fuel to be used, and its cost.

10. The kind of water available for the engine-boilers.

Climate. 11. Whether the dredger-boat will be exposed to rough seas or winds, extremes of climate, marine worms, and any particulars which will guide the choice of propelling power, anchors, cables, and other equipments.

Management. 12. Under whose management the dredging operations will be carried on, and the kind of workmen and superintendents available for managing.

13. The means of transport to the site of operations, and whether the dredger-boat is to be navigated complete to its destination or sent in pieces. **Transport to site.**

14. The facilities for repairs, and such other particulars as will determine the number of duplicate parts required. **Duplicate parts.** *See pages 41 & 180.*

Pile-drivers.

Pile-drivers are worked either by hand or by steam-power, the latter giving ten times as many blows as is possible with hand labour and at much less expense. The falling ram of a pile engine is generally of some weight between 8 and 20 cwt., the latter being very rarely exceeded. For lighter rams, "ringing-engines" only are used, the weight being lifted by a hand-rope passing round a pulley. The winch of a hand-machine is worked by single power, whatever the weight, as double-power would be too slow; the number of men being increased from two to five, according to the weight. Steam-machines are also worked by single-power, so as to obtain speed; and it is inexpedient to increase the weight of ram beyond that which the steam-engine is arranged for, as the additional weight can only be met by increasing the steam-pressure.

Ringing-engines. **Single power.** *See page 362.*

Suitability, how determined.

The suitability of a pile-driver depends not only on its action when working, but on various secondary points, such as portability, facility of adjustment and attachment. As pile-drivers have often to be pushed forward on a slight or overhanging stage, lightness is essential; and at the same time the apparatus must be stable enough to serve as a derrick for dragging and lifting the piles into position. The various automatic movements for catching and releasing the ram are now well understood, and are common to most pile-drivers, the more modern improvements being in the direction of portability, increased scope, driving diagonal as well as vertical piles, and such methods of construction as will allow of a pile being driven below the level of the stage on which the machine stands, without the interposition of a driving-piece or "dolly" between the falling ram and the pile head. Such machines are known as "telescope" pile-drivers.

See page 379. **Telescope pile-driver.**

Gauge-piles and walings.

Where a continuous wall of piling is required, as for a cofferdam, it is usual to drive first separate "gauge-piles" at intervals of about 15 ft., arranging these very exactly in the desired line. These piles are then connected by horizontal walings, so as to form a guide or frame-work within which to drive the continuous or sheet piling. The last pile in each bay is made of special width, so as to fit tightly into the space left for it, and as a key or wedge to squeeze all tightly and

Key-piles.

closely together. The proper driving of the piles greatly depends on the correctness of the preparatory work and on having the lower walings near the ground. Sometimes a ringing-engine or light machine worked from a barge is used for driving the advance piles, on which can then be constructed a staging for a heavier machine; but even for advance work of this sort, steam-power can often be employed with but little additional weight, by detaching the engine from the machine and leading only the chain to it. But on a suitable staging or even a floating barge, the weight of the engine is an advantage as affording stability. Sometimes the engine is complete with boiler, but in other cases, the steam is brought from a detached boiler, often from that of a portable engine.

Advance work and staging.

Pile points.

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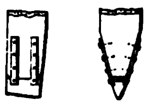

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The proper pointing of a pile has much to do with the correctness of the driving, for unless the point is true with the centre line of the pile, and the iron shoe also truly fixed, the pile is apt to go wrong. Gauge piles or staging piles should have diamond-shaped points, that is, tapered square exactly the same on the four sides. Any unevenness in this respect causes the pile to diverge from a vertical line. But for this reason, in sheet-piling the points are bevelled more on one side than on the other, so as to cause the pile to press against the preceding pile, so ensuring a close wall.

Dimensions and prices of pile-drivers.

Pile-driving machines are generally made from 35 to 40 ft. high, and a manual machine has generally a base about 8 ft. square. Including one 15-cwt. ram, such a machine would cost from £50 to £60, or if, as is sometimes preferred for export, the wood-work be omitted, about £30 less. The usual height of a steam-machine is 40. ft., the base is from 8 ft. to 10 ft. square, and the weight when fully equipped is from 6 to 7 tons. Such a machine costs from £250 to £350, or about £50 less if the wood-work be omitted. Higher or stronger machines are occasionally made for very large piles, and also for driving iron piles. For any but large machines, it is usual to furnish the base with wheels, so that it can move along a line of rails laid for the purpose, a gauge of 7 ft. or 8 ft. being generally most suitable.

Weight and fall of ram.

See pages 331 & 349.

Discrimination is needed to determine the most suitable weight of ram and height of fall. Generally a heavy ram and moderate fall will do more effective work than the same aggregate force with a lighter ram and greater fall. On the other hand, the energy of a heavy ram may be expended in crushing the pile instead of forcing it downwards.

How determined.

The thickness of the pile, the kind of wood, and the nature of the

ground are the principal points which determine the weight of the ram and its fall, but the depth of insertion, and the consequent friction to be overcome, have also to be considered, and for these reasons the ram is changed sometimes in the course of driving a single pile.

As much of the expense in pile-driving is in the cost of staging, of placing the machine, ringing and shoeing the piles and pitching them, the cost of driving would, if stated per foot, be more for a small depth to be driven than for a greater depth, as these preparatory expenses are about the same in any case. In any contract for pile-driving, these circumstances must be taken into consideration, and if it be desired to arrange a schedule, then it is better to specify first a fixed price per pile and then a rate per foot. But even this is not enough if the strata be unknown or variable, as the cost of driving obviously increases as the pile becomes tighter in the ground, and a higher rate beyond a certain depth becomes necessary. An experienced contractor is, however, often able to meet all these contingencies by an average price, or is willing to take the risk for a certain sum of money.

Cost of driving piles.

Preparatory expenses.

Schedule rates.

See page 27.

Diving apparatus, as used in engineering operations for enabling men to work under water, is of five principal kinds: the helmet and dress, the diving-bell, the air-lock bell, the air-cylinder, and the air-caissoon. The main circumstance which limits the application of all these systems is the depth of water. In the diving-helmet the air-supply must be of sufficient pressure to force open the escape-valve for the impure or already-breathed air against the head of water, and therefore the pressure from the air-pump must always slightly exceed that of the water, which is nearly $\frac{1}{2}$ lb. per square inch for each foot of depth ($43\frac{1}{4}$ lbs. for 100 ft.)

Diving apparatus classified.

Helmet and dress.

Air pressure.

Water pressure.

See page 76.

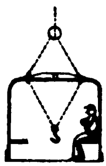
The improvements in the diving-helmet and dress have removed the risks which were unavoidable in the earlier and less perfect apparatus, and minimise the inconveniences of breathing under pressure, as the diver has now a ready means of controlling the air-supply. It is found that no difficulty arises up to a depth of 50 ft.; that a diver after a little practice can as well descend 80 ft.; and beyond this, up to 150 ft., the depth at which work can be conveniently carried on depends on the constitution of the men. There are many divers who cannot descend more than 80 ft. There are few who can endure more than 100 ft., and 150 ft. may be considered the maximum depth to which the strongest men will descend, although a few instances of endurance in a depth even of 200 ft. are

Limits of depth.

Ordinary and maximum depth.

recorded. Not only are the difficulties of breathing intensified at these great depths, but the pressure over the whole body becomes unendurable. The helmet, dress, air-pump, and other appurtenances forming a complete apparatus, as suitable for an engineer or contractor, costs from £100 to £120. The air-pump is the most expensive part of the apparatus, and as one set of pumps can, without proportionate extra expense, be made large enough for supplying two divers, a double equipment only costs about £150, but the pumps must be specially arranged for the purpose, to enable them to supply air at varying pressures, as of course the two divers will not be always exactly at the same depth. A light apparatus, such as is sometimes carried on board ship for examining the hull, and suitable for depths of 40 ft., can be purchased for about £60.

Cost of helmet apparatus.



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Diving-bells.

Diving-bells may be made either of cast or wrought-iron, and if of the latter, there is a ledge outside on which to place kentledge or other weights which force the descent. A diving-bell of ordinary size is 6 ft. long, 4 ft. 6 in. wide, and 5 ft. 10 in. high. Round the inside of the bell is a seat high enough to keep the men's feet clear of the water. There are generally four lenses of thick glass on the roof; there are of course openings or inlets for the air-tube, and there is a relief or safety valve. There are usually four suspending chains attached to strong eye-bolts passing through the roof, and from these eye-bolts loads can be suspended and deposited as the diver may direct.

Air pressure.

As a larger surface of water has to be held back, a more considerable escape from the mouth of the bell made good, and therefore a larger volume of pressure-air maintained than in a diving-helmet, larger pumps are necessary; but on the other hand the maximum pressure per inch which is required for divers in deep water does not occur in the bell, as the limit of depth within which men can safely work is much less. For, while a man can endure on the small surface in the helmet where the air supply is guided and controlled, a pressure to overcome a head of water, of from 80 to 150 ft., the pressure in a bell becomes oppressive beyond 50 ft., and 80 ft. may be taken as the greatest depth. Indeed, as diving-bells are generally employed for subaqueous structures, and not for the exploring and other miscellaneous work of a diver, the depth in the great majority of cases does not exceed 40 ft. A diving-bell complete with air-pumps and tubing, and with three tons of iron weights, costs about £200, but these prices do not include the cranes or other lifting

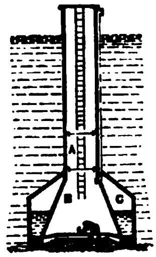
Limits of depth.

Cost of diving-bell.

apparatus. The cost and inconvenience of lifting and moving diving-bells greatly limits their use, the diver in helmet and dress is generally preferable; and where an air-chamber is necessary, the diving-bell has been superseded for many purposes by air-lock bells and air-caissoons.

Air-lock bells.

Air-lock bells resemble diving-bells in being open at the bottom and in having a working chamber filled with compressed air of force sufficient to hold back the water; but, unlike the ordinary diving-bell, they are always accessible from the top. The air-chamber B at the bottom is made of a size sufficient for the work to be done in it, and its height being limited to that convenient for the workmen, the space to be kept full of air is of moderate extent. Above the air-chamber there is a cylinder or tube, large enough for men to pass through, reaching above the surface of the water and open to the atmosphere; and at the junction of this tube with the air-bell below, or, in some cases, at the top of the tube, is a lock or chamber A with a door and air-cock at each end, so that as communication is opened either with the compressed air below or with the atmosphere above, the men can pass in and out, and excavated materials can pass also. The air-bell may be lowered into its place by chains from above, but the lowering, raising and moving from place to place are rendered easy by means of the displacement in the working air-chamber, and also in other spaces C provided for the purpose above, which not only are equal to the weight of the bell itself and appurtenances, but to suspended loads also. On the other hand, the air-spaces can be filled with water, and ballast weights attached, so that the buoyancy can be adjusted and controlled.



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Mode of working.

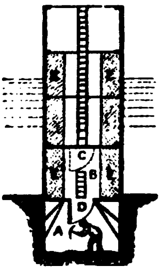
Buoyancy adjusted.

Air-cylinders.

Air-cylinders somewhat resemble the bell as just described, as they are open to the atmosphere above, and have a working chamber below with an air-lock between, but they are generally permanent structures. That is to say, they are to serve as bridge piers, and when by means of excavation in the working chamber they have reached a firm foundation, the chamber is filled with concrete, the air-lock is removed, the entire cylinder also filled with concrete, or left as an iron column to support the bridge above. If a base larger than the column is wanted to afford sufficient bearing on the ground, the working chamber may be made of larger diameter than the upper part. Cylinders are generally forced down by weights, an ordinary plan being to place iron or stone on a timber framing on the upper tier. But by this plan a cylinder is apt to become top-heavy, and

Bridge piers.

See BRIDGES, *Part I.*



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Cylinders of brickwork.

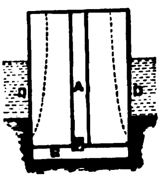
if the weights can be placed inside and low down, the sinking can be more safely effected. In such a case the lower tier may form a working chamber A, and the tier above an air-lock B; a solid ring of brick-work or concrete being built up to give weight and stability. When the cylinder has penetrated to the desired depth, the air-doors may be removed, and the cylinders filled up solid with concrete. Or it may, in some cases, be possible to still further simplify the process by omitting the outer iron casing above the air-chamber, and, instead, to build a cylinder of brick-work, the latter being built as on a floating caissoon, course by course as the caissoon sinks, an inner tube of iron allowing access to the air-chamber as in the air-lock bell. During the sinking of cylinders by the pneumatic system, if a very soft stratum be met with, the pumping may be reversed, a vacuum created, the material being forced into the cylinder by the atmospheric pressure, which at the same time, pressing on the outside of the cylinder, forces it downwards.

See also SAND-PUMPS, *page 411.*

Cost of apparatus. The pumps, air-doors, valves, and tubing suitable for an air-chamber 6 ft. high in a pier-cylinder 8 ft. diameter would cost about £300, and from this upwards there is a wide range, the power necessary in the pumps increasing rapidly with the volume of air to be supplied, and with the density or degree of compression as determined by the depth of water.

Air-caissoons. The *Air-caissoon* is an amplification of the air-cylinder, and is used where large foundations are needed. In this case, when the excavation is concluded, and the air-chamber B filled with concrete, a solid pier of concrete or masonry (as dotted) is built above it, and the tube

How made. A and air-lock F removed. The sides DD of the caissoon may be of iron or timber, or both combined, temporarily strutted inside with timber during the building of the pier within; or if it be built of concrete, walls only of moderate strength would be needed, the space within being kept filled with water till the concrete displaced it, the pressure of the water inside balancing that without. The most notable example of an air-caissoon occurred in the construction of the foundations of the St. Louis bridge over the Mississippi, where the air-chamber was 82 ft. long and 60 ft. wide, and the bridge subsequently built over the East River at New York.



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The experience gained in the building of these foundations is of

Limits of depth. great value. The air-pressure at a depth of 120 ft. proved fatal to the workmen, but it was found that healthy men could work safely at a depth of from 80 ft. to 90 ft. if only subjected to the pressure for

about an hour at a time, and if the change to the open air was made gradually. But 80 ft. is the maximum depth to which the system of air-caissoons can safely be reckoned on.

Advantage may be taken of the compressed air in cylinders and caissoons to work machines. Thus sand or mud may be removed by means of a pipe from the air-chamber below open to the atmosphere above. The spoil being heaped round the mouth of the pipe and a cock opened, the air-pressure will force the spoil upwards. Where rock has to be excavated, holes for explosives may be made by percussion rock-drills of the ordinary kind by means of the compresssed air, if a tube from the exhaust orifice of the drill-cylinder to the atmosphere above relieve the piston of back pressure. Of course where the compressed air is used for supplementary purposes of this kind the air-pumps must be equal to the extra demand.

Sand-pumps.

Rock-drills.

See page 391

In diving apparatus of all kinds it is of the utmost importance, for safety to the workmen, that the tubes, valves, and other parts should be of the best quality, kept in good order and tested periodically. The engineer or manufacturer to whom the design or choice of apparatus is entrusted should be fully informed of all the circumstances of the case, namely, of the purpose in view, of the other appliances with which the apparatus is to be combined, and of the depth of water.

Although considerable improvements have been made in the various pneumatic apparatus just described, such systems are necessarily troublesome and expensive, and while the helmet and dress are cheap and available for a variety of purposes, air-cylinders and caissoons should be used only when simpler methods are found to be too difficult or impracticable. The invention of automatic excavating-machines which can be worked from above, are in many cases rendering the use of compressed air unnecessary.

Pneumatic method expensive.

See page 385.

[*See also* STEAM-ENGINES: CRANES: *and in Part I.* RAILWAYS: HARBOURS AND DOCKS.]

CHAPTER XXVII.

PORTLAND CEMENT.

PORTLAND cement, since its first introduction about 1840–50, has grown rapidly in favour with engineers, and its manufacture has attained enormous proportions in England and elsewhere. The name is misleading, for the cement is not made at Portland, but was so designated at its first introduction, because the concrete made with it had a supposed resemblance to the well-known Portland stone. When mixed with sand and moistened with water, Portland cement binds stone or brickwork together with a strength and hardness unattainable by any other kind of mortar, but it is when made into concrete or *béton* that it has its highest value. By its use as a substitute for masonry, and especially from the manner it sets in water, and the facilities which it therefore affords for subaqueous structures, cement-concrete may be said to have revolutionized the art of the engineer.

Origin of name.

Strength and hardness.

See HARBOURS *and* DOCKS, *Part I.*

The ease with which the materials for concrete may be brought to the site of building works and there made into blocks of the desired form or weight, is an advantage which allows of building operations otherwise impossible. There is hardly any limit to the size of block that can be made, the difficulty arising only in the moving them. Cranes for lifting 30 tons are frequently provided on public works, but for heavier blocks special apparatus is contrived, or the blocks are floated on rafts or pontoons. Besides this, homogeneous walls of any length can be moulded *in situ* without being composed of separate blocks. New uses are continually being found for cement and concrete, whereby not only the cost of transport but the wages of skilled masons and bricklayers are saved.

See page 102, Part I.

See page 376.

New uses for cement.

See page 422.

Quality and cost, how determined.

The quality and cost of cement depend principally on the locality

where it is made, on the kind of materials there available, and on the methods of manufacture adopted. The best Portland cement is made from a mixture of chalk (carbonate of lime), with certain kinds of clay (silicate of alumina), in proportions, speaking broadly, ranging from about 3 to 4 of chalk to 1 of clay, according to the kind of chalk; and these materials (of which about two tons are needed for each ton of cement), having been thoroughly mixed, are calcined in a kiln and ground to powder.

Made of chalk and clay.

The principal Portland cement works in England are situated near London, on the rivers Thames and Medway, where there is a combination of advantages existing nowhere else in the world. The chalk and clay are found close together on or near the river bank, and yet quite separate, so that the proper proportions can be exactly measured; the coke from the numerous gas-works of London affords a cheap and plentiful supply of suitable fuel; and the situation of the factories allows the cement to be loaded into barges, coasting-vessels and export-ships at a trifling expense.

Cement-making in London.

See COKE, *page* 128.

There are many varieties of detail at all stages of manufacture; but up till 1880 the largest proportion of cement has been made by mixing the chalk and clay together in what is known as a wash-mill, in which they are stirred together in water by revolving harrows, and by causing the mixture, when thoroughly amalgamated into a consistency like milk, to flow into shallow reservoirs or "backs," from which the surface water is gradually allowed to flow away or dry up, till there only remains at the bottom what is known among English makers as "slurry" or "slip," of about the consistency of butter. To still further dry the slurry by mere exposure to the air would, in the English climate, take too long a time, and artificial heat is employed; an ordinary plan being to lay the slurry on drying-floors near the kilns. These drying-floors are heated in various ways: in some cement works by ordinary fires; in others, where coke is made, by heat from the coking-ovens; while in some cases, the heat given off by the calcining kilns during the process of burning and cooling is utilized in connection with the drying-floors. One modern method of drying the slurry is to pump it into a long chamber communicating with the top of the kilns in such a manner that the whole of the heat from the kiln passes through the chamber and over the slurry; and in some cases the chambers are covered with iron plates upon which a further quantity of slurry is dried.

Method of manufacture.

Mixing of the chalk and clay.

Drying of the slurry.

Drying-floors.

The slurry having been dried to a consistency approaching that of

ordinary chalk (but still containing much moisture), is then broken into pieces and placed with about an equal bulk of coke in a kiln and calcined; this operation of burning and that of afterwards cooling occupying about three days. The resulting "clinker," as it is called, is intensely hard and of a dark grey colour. The next process, after picking out and throwing aside all imperfectly burnt clinker, is to break it by rollers or by a stone-crushing machine into pieces about the size of a walnut; and it is then ground to powder between millstones, with almost as much care as that necessary for flour, and to the same fineness. Including the fuel for the engines, the total quantity of coal and coke required for all operations is about half a ton for each ton of cement.

The dried slurry calcined. **Clinker.** **Broken and ground.** **Fuel consumption.**

Continued attempts are made to cheapen and improve the foregoing plan of manufacture. Thus, it is endeavoured to avoid the long process of settling in backs (which in the English climate occupies from 4 to 10 weeks), by grinding the chalk and clay together between millstones directly from the wash-mills (where less water is used than in the ordinary process), and taking the resulting slurry or paste direct to the drying platforms. There is much to be said for and against this method. On the one hand, the large space occupied by the backs is saved, as well as the labour of digging out the deposit and carrying it to the drying-floor. Moreover, the particles when deposited in the backs, not being of equal gravity, tend to separate, and are not, after settling, so intimately mixed as when they flow out of the wash-mill. On the other hand, the amalgamation by grinding is more expensive; and the slurry, though containing less water than that from a wash-mill, yet when taken direct to the drying-floors, obviously requires more fuel in the evaporation of that water, which, in the ordinary method, partly flows away and is partly dried up by the sun. As the cement made according to either plan is found to fulfil the same conditions and to command (1880) the same price, the advantages of one over the other probably depend on the local circumstances of the manufacture, whether there is much space available for settling-backs, or whether the expense of acquiring land is not in particular cases better bestowed on grinding-machinery for the drier process. Improvements have been attempted in the various processes of mixing, drying, burning and grinding in all the countries where cement is made, and numerous inventions have been patented. These need not be further described here, but in regard to the grinding it may be said, that no plan of avoiding the

Improved methods of mixing. **Settling-backs avoided.** **Advantages.** **Disadvantages.** **Grinding by mill-stones.**

use of mill-stones has succeeded with cement any more than with flour.

Quality, how ascertained.

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Test briquettes.

The quality of Portland cement and its fitness for the purposes of the engineer are ascertained primarily by testing the tenacity of blocks of neat cement moulded for the purpose; and for convenience, and to allow of comparison, test-blocks of standard size have been established; the custom in England being to use briquettes 1½ in. thick, 3 in. wide at the ends, reduced to 1½ in the middle. These briquettes, after being moulded, are allowed to set for a certain time in a dry place, followed by immersion in water. The briquette, after this period of setting, is held at the ends and torn asunder, and breaks in the middle as the weakest place. Assuming that the test has been properly conducted, the strain necessary to break good English cement will range from 500 to 1,200 lbs., and this wide range of difference is not yet thoroughly understood, though it is probably due to variations in the testing as much as in the manufacture. It has been found that strength cannot be assured unless the cement be of a certain weight, and that in proportion to the weight of the cement does the importance of fine grinding increase. Therefore conditions in regard to these points also are demanded by engineers. The weight of cement ranges from 105 to 115 lbs. per imperial bushel (1·225 cubic feet), according to the thoroughness of the burning and the fineness of the grinding. The fineness is stated according to the mesh or sieve through which the cement will pass with a specified residue, the mesh ranging from 40 per inch (1,600 orifices per square inch), to 5,000 orifices per square inch. The maximum degree of fineness is adopted by some continental makers, but it is very doubtful if the increased cost of such fine grinding is met by any increased value in the cement.

Broken by tension.

Test by weight.

Test by fineness.

Usual test conditions in England.

A usual specification of quality in England is that which prescribes a test briquette of 2¼ in. sectional area, which shall after being moulded, remain 24 hours to set dry and for six days immediately afterwards in water, and then withstand a tensile strain of 300 lbs. per square inch (equal to 675 lbs. on the 2¼ in. briquette) before fracture; further that the cement shall weigh 112 lbs. to the bushel, and be of a fineness to pass through a mesh of 40 per inch or 1,600 to the square inch, with a residue of only 10 per cent.; or through a mesh of 2,500 to the inch, with a residue of 20 per cent. Cement which will fulfil these conditions may (1880) be considered of good merchantable quality, and it will generally be found that much

Ordinary merchantable quality.

of the cement supplied on such a specification by manufacturers of repute will really bear from 700 to 1,000 lbs. on the briquette, according to the skill or method of making and the manner of testing; but if these higher tests are prescribed as an essential condition, there is a risk that they may be satisfied at the expense of durability in the concrete.

The usual tests given above have been found sufficient for public works of magnitude and importance; and vast quantities of cement purchased for export on such a basis have proved satisfactory. But there is a tendency among some engineers to demand still higher standards both in regard to fineness and tenacity, and involving a greater weight also. Thus in England, breaking-strains of 350 and even 450 lbs. per inch (equal to from 780 to 1,000 lbs. on the 2¼ in. briquette) are sometimes demanded; and it is found that by care in mixing, and hard-burning, such a test can be satisfied at a trifling cost per ton above the nominal price, but certain risks are involved. These higher standards of quality have been set up by engineers and manufacturers in countries where the materials and fuel for cement are more costly than in England, and where, therefore, there is every inducement to obtain, by improving the quality, the maximum binding power from a given quantity of cement. In Germany not only is the high breaking-strain demanded, but in regard to fineness a mesh of over 5,000 per square inch is prescribed. The expediency of such high standards is to a large extent determined by secondary considerations. Thus, while on the Continent the materials are dear and labour is cheap, in England the reverse is the case, and any extra labour necessary to a higher quality may cost more than it is worth. For English cement is very cheap, and if compared with lime, or any cement other than Portland, is immensely superior. Moreover it is the opinion of many of the best English makers that this extreme fineness affords no advantage.

Higher tests demanded. **High breaking-strain.** **Why demanded.** **Extreme fineness.** **English cement still the best.**

When a reasonably good quality can be assured, it is in all trades generally desirable, in order to obtain the advantages of competition among numerous sellers, to conform to the ordinary commercial usages, for exceptional conditions may cost more than the apparent gain. But considerations such as these need qualifying, when the cost to the purchaser is much enhanced by expensive carriage or import duties, because if these are assessed by weight, they bear a less proportion to the original price as the quality is higher. If therefore it were found that higher standards of strength and quality could be

Conformity to usual conditions. **Cost enhanced by carriage and duty.**

met without inordinate cost, the foreign purchaser would gain by adopting them. For instance, if at the factory where ordinary cement is selling at 35s. per ton, a grade 10 per cent. higher could be obtained for 40s., the extra cost would be unduly high; but if, owing to carriage and other expenses, the ultimate price to the purchaser for the ordinary cement is 80s, then the gain of 10 per cent. in quality will be cheaply purchased for the additional 5s. per ton.

Renders high quality desirable.

See page 39.

See also COAL, *page 124.*

But it would not be safe with the present (1880) knowledge of cement, to act on considerations such as these. Increased strength can only be obtained by increasing the quantity of chalk or lime, and burning the cement very hard; and, although this may appear to involve only increased cost, actual harm may result, for there has not yet been sufficient experience to prove the durability of cement so made, and whether the extra quantity of lime may not, in the course of even a few years, tend to the deterioration of mortar or concrete so made. Moreover, the superiority which some cements seem to have as compared with other kinds, and the higher standards which have been set up in consequence, may to some extent arise from differences in the mode of testing. Unlike the testing of iron, brick, wood or other materials of construction demanding no preliminary treatment, cement requires much manipulation, and, at each of the numerous stages in the operation, a slight variation in treatment may involve wide differences of result, not caused by real differences of quality; and therefore, while the testing of cement, properly performed, is of great value, it is dangerous to draw conclusions unless the circumstances are alike in all the cases which are compared. The making of the briquettes requires great care and experience. The freshness or age of the cement, the temperature, the quantity and quality of water with which it is mixed, the manner of moulding the briquette and of removing it from the mould, the temperature in which the setting takes place, the length of time in setting, and whether in or out of water; all these circumstances affect the quality of the briquette. And when the briquettes are made, the manner of holding them during the test strain, and the manner and rapidity of applying and measuring the strain, also help to determine the result; and erroneous conclusions are drawn if any part of the process is imperfectly performed. It often happens that tests made by the same persons from the same barrel of cement, under apparently the same conditions, but with an interval of time between, will vary very considerably. It is endeavoured in

But increase of strength involves risk.

Deterioration in course of years.

Difference in testing.

Numerous stages.

Making of briquettes.

Setting.

Applying strain.

Contradictory tests.

the shape of the briquette and in the manner of gripping the ends to ensure that the strain upon the centre shall be direct and equable, and there are considerable differences of opinion among experts as to what is best in these respects. Special machines are made for applying and measuring the strain, such machines costing from £15 to £30. In some, the weight is applied on a graduated lever; in others, by the direct weight of a cistern of water, or a box weighted with small shot; both of which admit of the most gradual additions and exact measurements.

Testing machine.

How graduated.

Tests by purchaser uncertain.

While, on public works of large extent, it is worth much trouble to ensure by continual tests the proper quality of all the cement which is used, it is often difficult, when purchasing moderate quantities, especially in a foreign country or through an intermediary merchant when the user is not experienced in the art of testing, to imitate the tests made under other circumstances. After all the experiments that have been made, it may be said that the exact scientific reasons for the varying qualities of cement are still uncertain, and therefore, within prudent limits, it is often expedient to depend upon the reputation of the manufacturer as expressed in a well-known brand, making broad experiments from time to time with the concrete or mortar to prove not only the quality of the material but the efficiency of the treatment. There is little in the outward appearance of cement to tell its quality; and for this reason, and because of the difficulties and inconveniences of testing, the trade is one specially dependent on trade-mark or reputation. There are in the London district numerous makers of about equal eminence, but in foreign countries preference is given to the particular brand which has become known and liked. It is of course necessary to verify the genuineness of the mark, and to take care that the mark of one maker has not been used to cover the cement of another. Experienced makers on a large scale are presumably the best able to produce good cement, and it is through want of knowledge or from accidents in manufacture rather than from a desire to supply inferior cement that inferiority arises.

Quality ensured by brand.

See page 18.

See page 19.

Testing of cement in Germany.

Mixed with sand.

In Germany, it is considered better, instead of testing neat cement, to make the briquette of cement mixed with sand of certain quantity and fineness: it being asserted by those who advocate this plan that, as cement in real use is so mixed, the ultimate value for the purpose in view can only be ascertained by testing it under similar conditions. Against the plan it may be said that the difficulties and risks of vari-

ation which arise in the testing of neat cement are increased when another material is introduced. For while, on any one undertaking, where exactly the same kind of sand may possibly be assured, a useful standard of quality might be arrived at if the sand were carefully washed, sifted and measured, yet for general use and for comparison with some established standard, it is utterly inconclusive, because at different places and times the sand is not likely to be precisely similar in kind. **Inconclusive.**

Storage. Care is necessary in the storage and treatment of cement. It should of course be stored under cover, and it is all the better for being protected from a damp atmosphere and from extremes of temperature. Cement is not fit for use until it has been exposed to the air for some time; and as, in the press of business, the cement is sometimes packed and sent away from the factory directly it is ground without sufficient exposure to the air, it should not be used immediately after taking it from the casks or sacks, but should be spread out on a dry floor, so that the air may reach it for at least a week, and should if possible be turned over occasionally. **Cement must be air-slaked.**

Price of cement. The price of Portland cement at English factories has ranged during the ten years ending 1880, from 28s. to 38s. per ton exclusive of packing and transport. The expenses of packing bear a high proportion to the value of the cement. For carriage in the country of manufacture, it is usual to pack the cement in bags holding about 2 cwt., and these bags, costing about 9d. each, add about 7s. 6d. per ton to the cost of the cement; but part of the value is allowed to the purchaser if the sacks be returned in fair condition. But sacks, while sufficient for inland carriage, and even for short coasting voyages, do not afford sufficient protection for export and distant carriage, not only against rough handling in stowage or transhipment, but against moisture. **Packing in bags.** **Not sufficient for export.**

Packing in casks. Casks holding from 300 to 448 lbs. are generally used; and by the custom of the trade, sales are made per cask and not according to weight; but, the tare being known, the net weight is the real measure of value. Casks for holding 300 lbs., 400 lbs., and 448 lbs. weigh from about 20 lbs. to 25 lbs. respectively, and cost from about 2s. to 2s. 6d. each, so that at a time when cement is selling at the factory for 35s. per ton, a cask weighing 300 lbs. gross will cost 6s. 5d., this price being made up of 4s. 5d. for 280 lbs. of cement and 2s. for the cask; or 8s. 4d. for a cask of 400 lbs. Casks therefore add **Gross weight.** **Tare and net weight.**

from 14s. to 16s. per ton to the cost of cement, and it is seldom that the casks can be returned from abroad. In the absence of stipulations to the contrary, the casks are bound with wooden hoops, but they can be strongly bound with iron at an extra cost of about 3d. each. As a safeguard against wet, a lining of water-proof paper is sometimes added at a further expense of about 2d. It is of course necessary that cement, whether in sacks or casks, be protected from moisture; and carts, railway-wagons or barges which are covered are alone used for carriage.

Cost of casks.

Protection from moisture.

Methods of using.

It is not the purpose here to describe the methods of using cement. Good mortar is made with about 2 parts of sand to 1 of cement; fresh-water sand being better than sea-sand. Concrete is made generally with shingle or gravel, the proportions (including the above proportion of sand) to the cement, if of good English quality, varying from 5 to 1 to 12 to 1. Although sand of a loamy kind will make a good lime mortar, the materials for cement mortar, if its full strength be desired, should be perfectly free from soil of any kind, and in order to ensure this they should be washed. Sharp and clean river shingle or coarse gravel affords the best material, but coral, iron furnace-slag, broken bricks, and many other materials are also suitable, irregularity in form and slight porosity being an advantage. In mixing with sand or gravel, the proportions are not the same by weight as by measure; and as the cement with the sand forms the matrix which holds the shingle or other materials, it is bulk rather than weight which should determine the mixing. The concrete should be mixed dry and water applied and mixed immediately before depositing in place. Where concrete is deposited in water, it is necessary to place it through wooden shoots to prevent it being separated, and where the current is strong, the concrete may even be laid in place in canvas bags. Cement is sometimes described as "quick-setting" or "slow-setting," but any difference that really occurs in the using generally arises from one of two causes; either because the cement is used too fresh or because there is an excessive proportion of chalk in it. Both these causes render the concrete liable to deterioration. If, for any particular purpose, quick-setting is of importance, the manufacturer should be informed of it, as he may be able by modifying the usual ingredients or proportions and method of manufacture to meet it without harm. As a rule, slow-setting cement is the best.

Concrete.

Mortar.

Materials for concrete.

Proportions.

Setting in water.

Quick and slow setting.

The foregoing description applies only to real Portland cement;

but there are other cements which sometimes bear the name and come into competition with it. For, apart altogether from alterations or improvements in the manufacture of cement from chalk and clay, other systems are adopted where these materials are wanting. In comparing the cements made of different materials, it is important to bear in mind the economical or commercial conditions which attend the trade, for it is these, rather than any scientific difference of manufacture, which determine the competition. It is evident that the cost of land carriage in the country of manufacture, and, in the case of exported cement, the additional cost of packing in casks, and of sea carriage, must bear a high proportion to the cost at the factory of so heavy and cheap a commodity; and therefore there is every inducement to make cement in the countries and districts where it is wanted for use. There are few countries which do not possess materials from which some kind of cement can be made, but they are nowhere found under the same favourable conditions as in the neighbourhood of London. Instead of the chalk and clay lying separately, natural compounds are found, which, when calcined and ground, afford hydraulic cement of the Portland type. Examples of this method of manufacture are found in some of the central districts of England, on the northern coasts of Germany, and elsewhere. Much chalk is exported from London, and this is sometimes used with clay found in the locality as material for cement. But so cheap a material as chalk can only be imported profitably when the rates of carriage are very low; this being the case when the chalk is utilised as ballast. So much of the chalk, however, is evaporated in the course of manufacture, that carriage has to be paid on much unremunerative weight.

Imitations of Portland cement.

Competition, how determined.

Cement made in country of use.

Cement made from natural compounds.

Chalk exported for cement making.

But, while good mortar may be made from blue lias, and although the making of cement from natural compounds such as clayey limestone may save some of the expense of mixing, large deposits are hardly ever found of exactly the right proportions; and not only is more trouble necessary at certain parts of the process, but the cement obtained is liable to variations, and is generally deficient in some of the more important qualities of good cement; the direction and extent of the inferiority depending on which of the ingredients preponderate or are wanting in the material. Sometimes the cement will set in the same way as pure Portland, and appear like it, and yet have less than half its tenacity or binding power.

Blue lias mortar.

Not only however is cement made from compounds, as just

described, but, in some countries where such materials are entirely wanting, the cost of carriage of imported cement leads to the establishment of other systems. Lime in some shape or other is found in almost every country; and limestone or coral, or even marine shells, are used as a basis for cement if suitable clay is obtainable; these materials being generally mixed in a pug-mill. But the crushing of limestone or shells to powder is a tedious and expensive operation; and, when ground, the product so obtained cannot be so intimately mixed with clay as where chalk is used. Sometimes it is sought to avoid the grinding of these hard materials by first calcining them to render them friable; and, though this plan may answer where fuel is very cheap, it has not found much favour with manufacturers. It may be said therefore that no system of manufacture from substitutes such as the foregoing has as yet (1880) succeeded commercially in competing with the more ordinary English methods where the expenses of carriage and fuel are common to both, or even where they approximate. In countries, however, where the use of such substitutes is encouraged by protective duties on the better English cement, the question is no longer as to what is best and cheapest for the purpose in view, but (as is the necessary result of such a system) what will escape the duty. In England the advantages of Portland cement are becoming more and more appreciated. Lime, though preferable in mortar for ordinary building purposes, is being superseded by cement for making concrete, as the cement, unless burdened by very heavy cost of carriage, is found to be cheaper if measured by its cohesive power as well as by price. New uses are being continually found for cement. It is employed as an inner coating on the plates of iron ships; it may be used for jointing iron and stone, or even iron and iron, where metal cement cannot conveniently be applied; and it is particularly useful in filling up interstices and spaces in iron structures, which if inaccessible to the painter's brush, would soon be destroyed by rust if left unprotected. English-made cement is exported to every country in the world which is accessible by sea; the weekly output in the London district already (1880) has reached 15,000 tons, and as its advantages are becoming more widely known the trade is ever increasing.

Cement from limestone, coral or shells.

Limestone calcined.

See page 39.

Lime superseded by cement.

See page 39.

Cement used for coating iron.

See page 431.

Quantity made in London.

[*See also in Part I.*, HARBOURS AND DOCKS.]

CHAPTER XXVIII.

IRON ROOFS AND BUILDINGS.

IRON is used in the construction of roofs and buildings for different reasons. First, in cases where (though other materials may be obtainable) it is better than wood because of its greater durability and strength, or better than stone and brick because it occupies less space; conservatories, winter-gardens, market-buildings, railway-stations, drill-halls, and race-stands being examples. Secondly, where portability is of consequence, iron being lighter than other materials in proportion to strength; for instance, in countries where stone, brick, and timber are scarce, or where for want of skilled workmen they cannot be utilised at moderate cost. Thirdly, iron is preferred for its cheapness, as in the case of temporary houses, churches, warehouses, and other structures, which in most countries can be erected much more cheaply of iron than of brick or stone, and sometimes even more cheaply than of wood. For buildings such as these, which might be more durable of brick or stone than of iron, the desire for cheapness may arise from the temporary purpose of the building, or from the necessity of saving in price. In colonies and newly-settled districts, on public works and at mines, the period for which buildings will be required may be uncertain, and the minimum expenditure therefore may be the best; or the building may have to be erected on ground held by uncertain tenure, and facility in taking down and removal may be of importance. Even where permanency can be reckoned on, the need for cheapness may outweigh all other considerations. This may arise not from lack of capital, but because money has a high value, and the saving in interest which a low capital outlay permits may provide means for renewals afterwards. Thus, where a permanent stone build-

Reasons for using iron.

Strength and portability.

Cheapness.

Facility of removal.

Saving in capital outlay.

ing would cost £1,000 and a temporary iron structure only £500, the money saved might be worth 10 per cent. per annum to the proprietor; more than sufficient to replace the building from time to time, or to provide an accumulating fund for the permanent building at the end of a few years.

Rolled iron affords facilities.

The great development of iron buildings has arisen mainly from the facilities allowed by corrugated iron, and by the numerous forms of rolled iron available to the constructor, T, L, and I, being the most usual and convenient. Sheet iron acquires great strength by corrugation, the degree of stiffness depending principally on the depth of the fluting. This strength is so considerable that even thin sheets may be extended over a considerable area without framing or intermediate support. Advantage is taken of this to cover small roofs and sometimes spans up to 40 ft. with curved sheets, with only a tie-rod across. This plan is only suitable for temporary purposes, and for spans beyond 20 ft. would not be sufficiently strong against wind.

Rolled joists.

See page 148.

Rolled iron joists or beams are produced more cheaply than girders made of several pieces riveted together, and are useful for a variety of purposes, not only as parts of iron structures, but for buildings in all other respects of brick or stone. Rolled joists are not convenient for certain forms of attachment and are sometimes misapplied, especially where the cheaper kinds are subjected to bending or smithing. For beams deeper than 12 in. riveted girders are in most cases cheaper or better.


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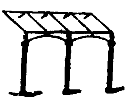
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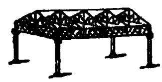
Where an iron roof has to be fixed on a building of brick or stone, continuous side walls generally allow the roof framing to be arranged in the most advantageous manner without regard to the supports. But in an iron building the positions of the columns have first to be considered. Thus, columns 8 ft. high may be placed as near together as 8 ft., for they may be made slender because numerous, and still be strong enough for the moderate height. But columns 20 ft. high would have to be stronger, and therefore it is economical to place them farther apart, so as to load them with a greater share of roofing. In the first case, a roof principal would probably be placed over each column, but in the second, as the spacing of these principals is determined by other reasons than those by which the columns are spaced—namely, by the span, the system of principal and the kind of covering material—economical construction may require that one or more principals be placed between each column, and to carry them, girders or arches must bridge the space between



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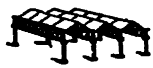

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the columns. Sometimes a space as free as possible is wanted below, or numerous doors or windows which hinder the placing of the columns; the latter may then be placed so far apart as to make the girders an important part of the building. Of course the further apart the supports, the more care must there be to afford the requisite stability to those on which the loading is concentrated. In wide buildings where intermediate columns or walls are undesirable, roof principals of great span—which would have to be lofty—may be avoided by supporting the roof framing on girders placed 30 ft. or 40 ft. apart, the roof principals being of these short spans.

Shape of roof depends on covering.

The disposition of the roof framing is partly determined by the nature of the covering material. Thus, sheets of corrugated iron are sufficiently strong in themselves to need supports only at intervals of 8 ft. to 12 ft. Zinc has much less strength, and has to be laid on wood rolls, which need supports every 6 or 7 ft. Glass is about the same as zinc in this respect, sash-bars of wood or iron taking the place of the wood rolls. Tiles and slates require laths every 10 or 12 in., these laths needing supports every 5 or 6 ft.

Roof principals.

Trussed roofs.

Arched roofs.

The choice between the many different kinds of roof framing depends on as varied considerations as does the choice of bridges. While the closeness of the framing may, as has been seen, depend upon the kind of covering, the shape of the "principals" is determined by various circumstances. Most principals are trusses or girders of some sort, but occasionally strong walls or side buildings form abutments which favour the use of arched roofs; or the latter may be preferred even without these facilities, and therefore at greater expense, for æsthetic reasons. Where there are no abutments and an arched form without trussing is preferred, the outward thrust may be withheld by a horizontal tie. Certain shapes are economical for large spans, because the divisions of length which the shape involves may accord with those usual in rolled iron, while such divisions in a smaller span might require too numerous and expensive connections. Other shapes, by their method of attachment to the columns or side walls, and by ending at one point in their junction with the supports, need some bracing or anchorage to the ground which in other kinds of principal is afforded by a wider junction, this latter method giving the stability necessary to a lofty building; others again are best suited to resist severe and one-sided wind-pressure, for trusses and arches well able to withstand a load equally applied may fail under a one-sided pressure. A preference between forms

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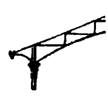

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equally appropriate in all other respects may depend upon the shape given to the ends of the building, gabled or sloped (hipped). Thus what are known as English roofs (247) allow of hip connections better than French roofs (249). The angle of slope of the roof is determined not only by the depth and strength of the principals or girders, but by the rainfall, the necessity of preventing leakage, and by the direction and force of the wind.


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Ventilation.


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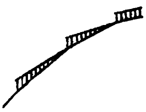
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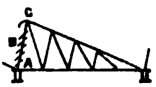
Ventilation has also to be considered, for if large openings are needed, shapes which would otherwise be suitable may need modification. Ventilation is generally provided at the top of the roof by raised lanterns or domes, but openings in the purlins are sometimes convenient or necessary. Roof principals with curved or polygonal top flanges are well suited to this arrangement. Openings may be also made under the eaves in the girders or spandrils which support the roof. Proper ventilation depends partly on the lower openings; and doors, windows, or special air gratings may have to be provided at a low level to ensure an upward draught.

Lighting.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Saw-shaped roofs.

See page 264.


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The manner of lighting also needs consideration, and it depends mainly on the purpose of the building and on the climate. Certain manufacturing trades require the maximum of light, and sometimes, therefore, buildings are erected with a particular aspect, and with roofs of irregular form, a northern light being generally preferred. The long side of the roof may be covered without any glazing, and the steep side may be partly (A to B) lighted by glass louvre-blades easily fixed or replaced, and the upper part B C left open for ventilation, but shielded by a projecting hood. A series of such spans supported on girders, or on columns or walls, may be conveniently arranged in the roofing of a large factory, and the horizontal tie of each principal may be made sufficiently strong as a girder to carry lines of shafting. A minor, but in large or lofty roofs an important point, is accessibility for painting and repairs; for the expense of maintenance may be considerably reduced if convenient access is left for replacing broken glass or for painting. Unless roof structures are periodically examined and painted they will rapidly deteriorate by rust, especially in a damp climate, or in places exposed to a vitiated atmosphere. The "ridge and furrow" system of roofing is convenient in the access it allows to every part of the covering. According to this plan, the purlins which rest on and connect the main ribs support a series of small roofs of from 7 to 15 ft. span, with slopes at right angles to the slope of the main roof.

The choice of covering material for roofs depends on climate and on the necessity for cheapness. Galvanised iron is effectual as a covering while it lasts, and, because of the great advantages its strength affords, it is more often used for iron roofs than anything else. Galvanised iron will last a long time in pure air, but not long in cities, railway-stations, or other places exposed to the fumes of coal, coke, or gas. But durability under any circumstances depends primarily on the quality of the sheets, and, secondly, on whether they are further protected by periodical painting. Zinc is more durable as a covering than iron which is only coated with zinc, but it is less often used because it costs more and adds nothing to the strength of the framing. Copper is even better than zinc, but is used very rarely because of expense; but on lofty domes and pinnacles, inaccessible for repairs, expense may well be incurred to ensure permanency in the covering of small areas. Zinc and copper when worn out have a value as old material, but old galvanised sheets are worthless. Tiles and bricks last longer, are better non-conductors of heat than metal, will preserve a more even temperature either in a hot or cold climate, and they are unaffected by a vitiated atmosphere. Tiles, which are made much lighter than formerly, are often used because of their pleasing colour and appearance. They are, however, heavier for transport than iron or zinc sheeting and require a stronger framework.

Choice of covering material.

Galvanised iron.

See page 145.

Zinc.

Copper.

Tiles and bricks.

All the covering materials above described may with advantage be laid on boarding, which not only strengthens the roof but increases its efficiency against heat, cold, rain, and snow. Some of the cost of the boarding is saved by the wider spacing of the framing that may be ventured on. Sometimes the boarding is not laid immediately under the outer covering, but with an air space of 9 in. or 12 in. between, this serving in hot or cold climates as a protection from the extreme temperature outside.

Inner lining of boarding.

Double covering.

Glass has been cheapened by improvements in manufacture; large panes may be obtained without inordinate cost; and there is more variety in kind. For export to foreign countries the cost is greatly increased by the risks of breakage, and so excessive sometimes are the losses from this cause that twice the quantity needed according to the size of the roof has to be sent before sufficient arrives in safety. These losses arise for the most part from preventible causes. In the first place the glass must be of good quality and well annealed; and only a moderate number of panes placed together in one wooden box.

Glass.

Breakage.

Packing for shipment.

Two, or even three, small boxes of glass thus packed may then be enclosed in a larger case with padding of some sort. Cases or crates so arranged will withstand railway or sea carriage, if the cases are carefully handled and stowed. The panes of glass are arranged in the cases so that they stand edgewise, and breakages arise principally from the laying of cases so that the panes are horizontal, when they are not so able to withstand shocks, especially if the panes are of large size. In the transport of glass the ordinary instructions to carriers are often insufficient, nor will marine insurance cover breakage. **Special precautions.** Special precautions should be taken at each place of transfer or transhipment to see that the cases are carefully handled and properly stowed.

Value of roofs according to strength. The value of a structure obviously depends on the strength of its various parts. A certain quality of material being first assumed, designs are then based upon these assumptions, or rules deduced from them, in regard to the maximum strains the buildings may have to endure, such as the loading on floors, the wind and snow pressure on roofs, and the strains caused by the form and weight of the structure itself; and then a certain factor of safety is calculated, 3, 4, or 5 to 1 as the case may be, according to the nature of the service and other circumstances of the case. Cheapness may therefore be obtained by venturing on a low margin of safety without any immediate appearance of inferiority, unless the strength of the various parts and members be measured, for the building may still be strong enough for its immediate purpose. If it were absolutely certain that a structure were strong enough to resist double the maximum strain that might come upon it, it might appear extravagant to go further, for the wasting of more than half the strength by rust, even in a long term of years, need not be anticipated under ordinary care. But every structure, however well made, has its weakest part, and when failure ultimately comes, either from long service or from accident, it will almost always **Causes of failure.** occur from some hidden flaw or some defective or missing fastening, long before the strains nominally provided for are felt over the whole building. Indeed it is because of contingencies of this kind that a factor of safety so high as is adopted by engineers **Deterioration.** is used in calculating strength; and it is only after some years' service, when weakened by vibration, changes of temperature, and wasting by rust, that the real value of precautions becomes apparent. The fact that a roof or building has been successfully erected, and has served

its purpose for a few years, does not alone justify an exact imitation of it, for the high wind or other exceptional circumstance which is to prove its stability may not then have occurred.

The harm which undue economy in material may do depends a good deal on the care with which the structure is periodically painted. Wasting by rust necessarily tells sooner on thin than on thick iron. All parts of an iron structure should be accessible to the painter's brush, or else be protected from the air by being built into masonry, brickwork, concrete, or cement. Sometimes cheapness is sought by using galvanised sheet-iron extremely thin. The thickness is denoted by the number of the gauge, the thinner sheets having the higher numbers. Thus corrugated sheets of No. 18 gauge weigh about 2·8 lbs. per square foot, No. 20 gauge 2·24 lbs. per foot, No. 22 gauge 1·85 lbs. per foot, and No. 24 gauge 1·5 lbs. per foot. The durability of such sheeting may be increased by painting it to protect it from that commencement of oxidation of the iron at defective places which, occurring as it must do sooner or later, will rapidly spread and destroy the iron. In England it is customary to use for good work sheets of No. 18 or even No. 16 B.W.G., but for export, sheets of Nos. 22, 24, and even 26 are more usual. In pure air these are long enduring if the quality be good, and full advantage may be taken of the great strength afforded even by thin iron when corrugated. But these thinner sheets are easily pierced, a surface crack or scratch of the zinc allows the commencement of rust, the crack grows into a serious rent and the sheets become worthless. But in regard to endurance against rust, good iron well galvanised will last longer than thicker sheets of inferior quality.

Ironwork painted.

Or protected from air.

Galvanised sheets painted.

See page 145.

Destruction by rust.

But while thickness and weight of parts afford one ready means of comparing the values of iron structures, the strength of a building depends also on the skilful disposition of the parts. As an iron roof is composed of numerous members, these must be arranged so as to resist and transmit the strains in the most effectual manner; and if one member be weaker than another the strength of the others will be of little avail. It has sometimes happened that roofs have been designed to sustain only vertical distributed loads, and if one-sided pressure, as from wind or drifted snow bear upon the roof, parts designed to resist tension only may become compressed and fail. The stability of a roof therefore depends a good deal on the secondary parts, such as wind-ties and bracing, which only come into play under exceptional loadings or pressure. An iron structure well

Arrangement of roof parts.

Wind-ties and bracing.

designed in other respects may be defective in its connections, and the strength of its members rendered inoperative by the weakness or unskilful arrangement of the fastenings. When a saving in weight is of great importance, as for distant carriage or to avoid import duties, high-quality material skilfully disposed will well repay an extra expenditure to obtain it. The importance of these considerations increases with the span and height of a roof or building, and especially if it be of peculiar or difficult shape. If the relative cost and strength of steel and iron be taken into account, steel seldom offers any advantages over iron except for spans over 150 ft., or where difficult land carriage makes saving in weight of great importance.

Steel roofs.

Assuming that an iron structure has been well designed, and that a good quality of material is ensured, the value then depends on the quality of the workmanship. First, in regard to the setting out of the various parts. Time and care bestowed on this are well repaid, not only in the manufacture, but in the erection and durability afterwards. In a roof there is generally a great repetition of similar parts, and these should be made so exactly alike as to be interchangeable. A few spare or duplicate parts to allow for loss or breakage will then be available; while, if each piece will fit only into its own place the cost and trouble of erection are much increased. Good or bad workmanship is specially discernible in the connections. As has been already stated, these must be well designed, but even then, if not well made, some of them will probably be inefficient. For instance, although all rivets should be perfectly tight, there are positions where bolts or pins may fit with approximate accuracy only; holding-down bolts, for instance, if they are well screwed down; and such looseness may even be necessary to allow of adjustment in erection. But there are other positions where tightness is of the utmost importance. For although the very great exactitude needed in a steam-engine or machine is seldom wanted in an iron building, there are places where holes must be drilled and bolts turned with great accuracy, in order to transmit properly the strains passing through them; this care being especially necessary where more than one bolt is in the same connection. There may be more trouble in erecting a building with tight fastenings, but if the parts have been properly set out such trouble is well bestowed.

Workmanship.

Interchangeable parts.

Fitting of rivets and bolts.

Drilled holes.

See page 328.

Tight fastenings.

Jointing of surfaces.

Not only fastenings but surfaces must sometimes be fitted with great accuracy. Where iron comes in contact with stone or concrete, the inequalities of surface may be made good with lead, iron-cement,

Portland cement, or bitumenised felt; wood, if joined to iron, will adapt itself to the harder material; but iron and iron will not in certain positions fit properly unless the surfaces are faced in the lathe or planing-machine. As an example, this is the case especially in a tier of columns for a building with upper floors. The strength of connecting parts, although skilfully designed, is sometimes reduced one-half by bad fitting, and the evil results tend to increase, because the parts of a structure so made are liable to move or shake under loading or wind pressure; excessive strains come upon individual fastenings, till at last, when bolts have been repeatedly bent backwards and forwards and wasted by the rust which too free a play allows, they break, while if they had been tightly fitted, and had had only their fair share of work, the structure would have been homogeneous and immovable. Machine processes are now so cheaply performed that the saving in first cost by the neglect of such precautions is only trifling.

Planed joints.

Strength reduced by bad fitting.

Failure sometimes arises by imitating a design which was originally carried out with due regard to the circumstances enumerated in the preceding pages, the knowledge or appreciation of the precautions necessary being wanting in those who repeat the design; or even where the work is well done, failure may arise by applying the same design under circumstances not exactly similar. The importance of the suggestions just given depends to a great extent on the permanency required, for if a building is only needed for a temporary purpose it may be inexpedient to provide too liberally for contingencies or durability. But even then a saving may be dearly obtained; for instance, by preferring a building 5 per cent. cheaper than another which may be 20 per cent. better.

Designs wrongly imitated.

Durability not always necessary.

After all the conditions of stability have been satisfied, the value of an iron structure for any but the barest utilitarian purpose depends upon its style or finish. Much of the prejudice against the use of iron arises from inelegant design or from the coarse way in which it is carried out. An examination of the iron structures in a large city will show how great are the differences in this respect. In ornamental cast-iron, for instance, the employment of an artist modeller to make the patterns may not add 1 per cent. to the cost, and yet afford a pleasing appearance which would otherwise be wanting. And in the processes of the iron-foundry skill and care are necessary to produce good castings. Again, in the foliage of a column capital, a good design may involve bold relief or "undercut," which requires

Style and finish.

Artist modellers.

Undercut ornament.

care and expense in the manufacture. Too often such designs are carried out in a rude manner. Good patterns are the first essential, then suitable pig-iron, and finally, capable moulders. Even where drawings and specifications are obeyed in all other respects, the close competition of manufacturers and the tendency to measure cheapness by price only, lead to the employment for fine or difficult work of workmen accustomed only to rough or simple castings. Even the plain surface of a large casting or the tapering shaft of a column look well or ill according to the skill in moulding, while column capitals or light spandrils afford more conspicuous opportunities for workmanship.

Skilful moulding.

And casting.

Neatness in wrought ironwork.

In wrought-iron also, a good appearance depends upon the neatness with which the various plates and bars are joined together, edges planed or trimmed, and rivets hammered. The extra expense which such care involves may sometimes be saved in other directions by skill in design to avoid too numerous or costly shapes of iron, unnecessary smithing, and complications in the connections. Simplicity in these respects is generally best as well as cheapest.

Fireproof buildings.

Term misapplied.

Fireproof buildings are generally made wholly or in part of iron, but buildings so-called often fail in practice. Misapprehension frequently arises from the different uses of the term. Iron and stone are fire-proof in the sense that they are uninflammable, but they are not proof against fire. That is to say, a building with walls of brick or stone, columns of iron, floors of concrete arches on iron joists, and staircases of stone, and with little or no woodwork, will not catch fire if free from combustibles; and even a small fire will go out for want of fuel, and will do little or no damage. But such a building, if filled with combustible goods, or even with much wood furniture or fittings, or if surrounded by inflammable buildings, may fail if fire occurs. Few kinds of stone will endure intense heat without crumbling away, and bricks of ordinary clay, though they will retain their strength at a greater heat than will iron, fuse or crumble under intense heat, though they will generally outlast a fire if the ironwork be protected. Cast or wrought iron, subjected to the heat of boiling water 212° (Fahr.) loses 15 per cent. of its strength, and at the temperature of molten lead has hardly any strength at all. And even under less heat, the sudden cooling from the water-jet of a fire-engine may cause cast iron to break. For these reasons wood, if of considerable thickness, is under certain

Stone, brick, and iron fail under heat.

circumstances better than exposed iron to resist fire, because, though inflammable, it is a bad conductor of heat and may retain part of its strength to the end, and may outlast the surrounding fire.

This however does not imply that wood structures are more fireproof than well-designed iron structures. A building cannot be properly designed to resist fire unless its purpose be known; and if, from the nature of its contents, a fire occurring inside would subject it to intense heat, then it must be constructed more or less like a furnace to resist it. One plan which minimises the effect of fire is to localise it by dividing a building into numerous rooms, separated by brick walls and iron doors strong enough to resist a fire in any one chamber till the combustibles are consumed, but this can only be effected by either avoiding iron columns altogether or by protecting them with some material which will resist great heat. Special kinds of concrete serve this purpose, and columns and girders encased with it will retain their strength and stability even though surrounded by intense heat. Such concrete, though it may not serve some of the purposes of that made from Portland cement, is very strong, and serves admirably for arched floors on iron joists; and if the latter be entirely embedded in it, a building completely fireproof may be obtained. Arches of 10-ft. span, with a rise of only 10 in., and only 5 in. thick at the crown, will sustain a working load of 2 cwt. per square foot; and narrower or wider spans may be similarly constructed with proportionate dimensions. Not only cellars, corridors, floors, and ceilings may be so constructed, but arched and domed roofs also. This system of construction is specially suitable for the staircases and corridors of theatres, schools, and public buildings, as well as for warehouses.

Buildings adapted to resist heat.

Divided by brick walls.

Iron protected from heat.

By special concrete.

Strength of concrete floors.

See PORTLAND CEMENT, *Chap. XXVII.*

In regard to the *Cost* of iron roofs and buildings there are wide limits within which the price for a structure of given size may be varied according to strength and quality. This is the case to some extent even where competitive prices are based upon a common design with prescribed dimensions and thickness of parts; but in cases where merely the length, breadth, and height are given by the purchaser and the details are left to the manufacturer, the range of possible difference is greater, and discrimination is needed to compare the real value of what is offered, or to decide which is really the cheapest. Care in this respect, which is necessary in the purchase of all engineering commodities, is peculiarly so in the

Cost of iron roofs and buildings.

Wide differences.

case of iron roofs and buildings. A large proportion of those which are made, especially those for export, are for temporary use, or at any rate have cheapness as the first consideration; therefore a certain style of strength, workmanship, and finish have become usual which are sufficient for the limited purpose in view. But such methods, which may be suitable for warehouse sheds or temporary houses, are quite inadequate for permanent structures like market buildings or railway-stations, and a comparison of prices according to the area covered between the two classes of buildings is fallacious.

Fallacious comparisons.

Quality of materials.

First, in regard to the quality of material. Without any difference in appearance, the value of cast-iron varies 10s. per ton, wrought-iron £1 to £3 per ton, and galvanised sheet-iron or zinc £2 to £5 per ton. The inferiority shows itself when these materials are subjected to severe or sudden strains, and if they then prove sufficient it is because their weight and thickness are in excess of what would be necessary in materials of better quality. The testing of iron requires care and attention not easily given in the ordinary purchase of structures, but a purchaser may be partly guided by the district where the iron is made, by the brand or name of the original producer of it, and by the reputation of the manufacturer of the roof or building. And in this latter respect the kind of building should be borne in mind, for there is much subdivision in trades, and makers of repute for one class of building may be ill-suited for another class.

Testing of iron.

See pages 133 & 137.

Prices cannot be tabulated.

See page 14.

Iron roofs and buildings cannot be tabulated in regard to price like machines or apparatus constantly alike, for it is seldom that the same circumstances combine more than once, or that exactly the same design can be repeated. Moreover, as the value of material has a much higher relation to the total cost than in the case of steam-engines or machines, fluctuations in the selling price of iron cause corresponding and continual fluctuations in the prices of the structures. It is sometimes attempted to value iron buildings according to their area, but for the above reasons prices so stated must be subject to considerable modification. The unit of size adopted in England is generally the "square" of 100 superficial feet, but as the strength and weight of roofs per foot increase with the span, the cost per square for roofs or buildings alike in other respects alters with the size. An increase in height must also obviously increase the cost; but if it be attempted to tabulate according to the volume or cubic contents, numerous circumstances render fixed rates inapplicable.

See page 33.

Price stated per square of 100 ft.

It is, however, possible to separate the parts of iron structures so

as to obtain a basis for estimating cost. First, in regard to weight: when pig-iron costs £4 per ton, iron columns and other cast-iron parts fitted for a building cost from £9 to £12 per ton; but if the design be complicated, or the parts very light or ornamental, these rates may be considerably increased. Wrought-iron parts, such as girders, will cost from £15 to £18 per ton at a time when iron plates cost £10 per ton, and lighter parts, as in roof-work, will cost £17 to £24 per ton.

Prices per ton. **Cast iron.** **Wrought iron.**

Wrought-iron roofing, if considered alone, may be approximately valued according to span, although every circumstance of difference must be taken into account before the rate for one roof can be exactly applied to another. Omitting very small roofs, it will be found that the framing of trussed roofs, exclusive of supports and of covering, will weigh from 5 to 6 cwt. per square (measured horizontally) for spans between 40 and 50 ft.; 6 to 8 cwt. per square for spans between 50 and 60 ft.; 7 to 9 cwt. for 80 ft.; and 8 to 12 cwt. for 100 ft. The rates of cost per ton are stated above. The lightest framing is that for a covering of corrugated iron, because it imposes little weight and by its strength renders unnecessary the closer supports which other materials require. Corrugated sheeting weighs from 150 lbs. to 300 lbs. per square according to thickness, the prices fluctuating considerably according to the current value of iron and zinc. In calculating the cost of corrugated iron for the sides of buildings, provision must be made for framing between the columns, although this is almost or entirely omitted in the case of huts or small sheds. Exclusive of the cost of the main framework, galvanised corrugated iron covering costs from £2 to £4 per square; zinc, £3 to £5; tiles, £3 to £4; slates, £3 to £5; and glass, £4 to £7, these rates including the subsidiary supports.

Value according to span. **Weight per square.** **Cost of galvanised covering per square.**

The smallest iron buildings are those used as huts and cottages, and such buildings 12 ft. to 20 ft. long, 10 to 15 ft. wide, and 7 or 8 ft. high to the eaves, will cost from £20 to £25 per square, or from £25 to £60 each, including doors and windows. But prices according to area are misleading for such small buildings.

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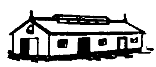
Huts.

Plain storehouses 12 ft. high to the eaves cost from £8 to £15 per square, if unenclosed, and from £12 to £20 if enclosed; but from £20 to £30 per square is needed when the sides are from 12 to 20 ft. high, and numerous or strong windows, doors, and ventilating fittings are required. The cost will obviously vary also according to the solidity of the supports, thickness of the sides and covering,



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Storehouses.

and the general style of workmanship. Dwelling-houses of iron are generally for temporary purposes, and are made light and cheap accordingly, but there are countries where strong permanent buildings can be erected with advantage and a sufficient price paid to ensure durability and elegance. Thus for a tropical climate, like that of India and parts of South America, dwelling-houses or bungalows can be built almost entirely of iron, but with thicker walls than is usual in temporary houses. That is to say, there may be an inner lining of wood with a space between it and the outer iron, which may either be left open or filled with concrete. The doors and windows would also be double. Buildings of this sort, well constructed and divided into dwelling-rooms, bed-rooms, bath-rooms, stables, and servants' quarters would cover from 40 to 60 squares, including verandah, and would cost about £50 per square, including wood and canvas lining, and all structural fittings.

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Bungalow.

Cost of permanent buildings.

See MARKETS *in Part I.*

It is impossible and would be misleading to lay down any rules for more important structures, such as markets and railway-stations, as when a particular case arises there are local circumstances of difference which render previous estimates inapplicable, the combination of masonry and brickwork with the ironwork and of subsidiary buildings and accessories increasing the difficulty of specifying the cost of ironwork alone. It is well to remember that the cost per square of the supporting framework increases with the height, and the cost per square of roofing with the span; that buildings open at the sides are cheaper than those enclosed; simple shapes in which the parts repeat cheaper than those of irregular shape; and besides these primary points, that the system of ventilation, the number of doors, windows and other accessory parts, and the degree of ornament have also to be considered.

Cause of difference.

Large span roofs.

Spans larger than 100 ft. do not occur frequently, as it is generally found better when a wide enclosure is required to have two or more spans. In market buildings the spans seldom exceed 60 ft.; in railway-stations the absence of intermediate columns is an advantage in the arrangement of rail lines and marshalling the traffic, but except in the case of large terminal stations in cities, spans of about 100 feet are found most suitable. The largest span yet (1880) constructed is 240 ft., but though such buildings may be imposing from the inside, it is very difficult to give them a pleasing appearance outside.

Railway-station roofs.

Railway-station roofs between 80 ft. and 150 ft. cost from £14 to £25 per square, including erection and covering, but beyond

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See page 425.

these spans and up to 240 ft. the cost of the station roofs erected in England during the thirty years ending 1880 has ranged from £25 to £50 per square. Under ordinary circumstances, and with iron at average rates, the cost of roofs between 150 ft. and 240 ft. span need not be more than from £20 to £35 per square, the greater cost, as just stated, having been caused by some of the following reasons—a form of construction involving much material or expensive workmanship; irregularity in the shape of the building; special expense in the covering, such as much and thick zinc, large panes of glass and strong iron sash-bars; the additions of gable ends or screens; and the occurrence of high prices for material. Where in wide buildings the presence of columns is alone objected to, roof trusses of moderate space may be, as already described, supported on girders, and in some cases the roof is placed upon the lower flange of the girders so that the latter are not conspicuous from the inside of the building. There is however the disadvantage in this plan that part of the structure is unnecessarily exposed to the weather, the numerous small roofs hold much snow and dirt, the rain gutters are numerous, needing much attention, and in buildings of large area the low roof renders ventilation difficult.

Design depends on circumstances.

As already stated on page 425, the proper design for an iron roof or building and an estimate of cost can only be made on the basis of full information, which should be given on the following points:—

Purpose.

The purpose of the building; whether for permanent or temporary use; and whether the design is to be plain or ornamental.

Size.

The dimensions of length, width, and height.

Open or enclosed.

Whether the building is to be open at the sides or enclosed, and if enclosed, whether by brickwork, wood, or iron.

Accessories.

The number, description, and dimensions of doors, windows, and other accessories.

Lighting.

The position in which lighting in the roof is required.

Climate.

The nature of the climate, the kind of roof covering required, and particulars in regard to rain, snow, wind, and ventilators, rain-gutters and pipes.

If of more than one storey, the number and height of each, and the loading that is to be provided for on the upper floors.

[*See also* IRON *and* STEEL, *and in Part I.* BRIDGES, MARKETS.]

CHAPTER XXIX.

LIGHTHOUSES.

Lighthouse engineers.

THE construction of Lighthouses and the methods of illumination have been developed by engineers who have devoted themselves to this special branch of science, and it is only intended here to point out the leading circumstances which have to be considered in establishing them, and which determine cost. The improvements that have been made in optical apparatus have rendered beacon lights more powerful and effective than formerly; but though the cost of this apparatus may be easily ascertained and tabulated according to the kind and range of light required, such cost in many cases bears but a small proportion to the total expenditure. The cost of the supporting structure and other subsidiary parts is sometimes not only greater than that of the lantern and light, but more uncertain, because dependent entirely on local conditions to which general statements of expense will not apply.

Cost of lighthouses uncertain.

While, however, the actual illuminating apparatus may thus form only one part of the project, it is of course that which is the object in view, which has therefore first to be considered, and to which the other parts must be adapted. The distance to which the light is to be visible is the first circumstance, and the one—other things being equal—which determines cost. The longest range is generally given to lights sighted by vessels approaching from beyond sea. The distance to which the light is to be visible determines the two principal points in the design, namely, the height of the tower and the intensity of the illumination. A light 30 ft. high above the sea level is, if powerful enough, visible for 8 miles; one 100 ft. high, about 13 miles; one

Range of light.

Height of tower.

150 ft. high, 14 miles; one 200 ft. high, 18 miles, and so on. Where the lighthouse is situated on a cliff, the necessary elevation is of course more easily obtained than where, as on a shoal or reef, a tower of the full height has to be built up from the sea level. So costly does a high tower sometimes become, that a light of less range has often to be accepted, on the score of expense only. A great height is often a disadvantage on a shore liable to fogs, for a light which might be visible at a lower level may be obscured by the fog above. On the other hand, where towers serve as landmarks during the day, they are sometimes made higher than is required for the range of the light. It is very seldom that a height above the sea of more than 150 ft. is desirable, and 200 ft. may be considered the maximum.

High lights obscured by fogs.

The greatest modern improvement in lighthouse illumination has been the substitution of the dioptric system, or the refraction of light by means of glass lenses, for the earlier catoptric system by which light is reflected by polished metallic mirrors. Lights of whichever kind are divided, according to their intensity, into 6 orders (sometimes subdivided or extended) of which the 1st, 2nd, and 3rd are the only ones used for important sea-lights, the other and less powerful being used for harbour-lights, or local service only. The distance to which a light is visible depends on various conditions which are liable to modification, according to the exact kind of light adopted, and other circumstances. The character given to a light, apart from its intensity, is determined by what is considered necessary to distinguish it from others. The different kinds adopted are—Fixed lights, Fixed lights varied by flashes, Revolving lights gradual, Flashing lights quickly but gradual, Intermittent lights without any gradual change, Intermittent for unequal periods, Coloured lights. The last named are seldom used except for harbour or local service. But besides these there are double lights, one above the other in the same tower, or side by side on separate towers.

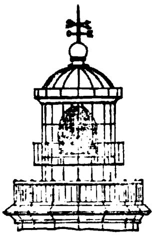
Dioptric system.

Lights divided into six orders.

Lights of various characters.

A certain diameter of lantern is necessary to each order, the 1st, 2nd, and 3rd having about 12 ft., 10 ft., and 8 ft. respectively; the 4th order, 6 ft.; and the 5th and 6th orders about 5 ft. The cost of the lantern depends on the diameter, but the cost of the optical apparatus depends not only on its rank, but also on the area within which the light is to be visible. With a fixed light the maximum expense is for an apparatus illumining the complete circle of 360°, but as the principal item of cost is in the numerous prisms for the lens apparatus with their subsidiary parts, all of which can be

Diameter of lantern.



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diminished as the arc becomes smaller, the cost is greatly reduced when only a narrow beam of illumination is required. Or even when the complete circle is required, the light—as when situated at the head of a gulf, or near the shore—may be concentrated most strongly in one direction, less expensive apparatus sufficing for the lesser distance in all other directions. A revolving light may be made the most powerful of all, for the light abstracted in the apparatus from the dark intervals may be made to contribute a proportionate increase of brilliancy. Therefore, while an all-round light may be preferable for other reasons, important coast lights which are sighted first by vessels from beyond sea are frequently made as revolving lights to obtain the maximum intensity. Thus in a light of the 1st order, with a narrow beam of 6°, a flash may be obtained of intensity eight times that of the fixed light.

Revolving lights.

Diameter of tower.

The height of the tower being determined by the range of distance required, its diameter depends partly on what is necessary for stability, and partly on the diameter of the lantern. The shape of tower, and the material of which it is composed, depend on the nature of the foundations, on the forces of wind or wave that it will have to withstand, and on the materials obtainable in the locality. In exposed situations nothing has proved so good and permanent as masonry, the great weight of stone towers giving them a stability against the waves; and in countries where suitable stone is wanting, it might even be expedient to bring the stone from a distant country. But the experience gained with Portland cement and concrete has shown that it may be safely applied to lighthouses. While, however, the cohesion and weight of concrete may render it suitable in many cases, either alone or in combination with ironwork, it is not so suitable as stone for towers exposed to the waves, because, for facility in erection the blocks must be kept within a certain weight, and therefore of a limited size, fitted and fastened together in a manner for which stone is better suited than concrete.

Masonry towers.

Concrete.

See page 412.

Iron towers.

It is seldom that iron cannot be adapted if necessary, and in cases where the foundations are not good, it may be the best or only suitable material. Thus on sand banks or mud shoals, screw-piles have proved effective for lighthouses as for other structures similarly situated. But as towers built of iron framework are not so well adapted as stone towers for dwelling rooms, iron is best used in those cases where detached storehouses and dwellings can be conveniently erected.

Screw piles.

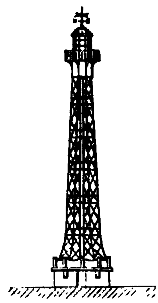
See page 116, Part I.

In all structures exposed to the wind and the waves, it is best to avoid the shocks by exposing as little surface as possible to their direct action, and while in masonry towers this is done by having a smooth circular shaft with no angles or corners opposed to the wind and waves, in a tower made of iron columns the same result is attained, sometimes by adopting the shape of a masonry tower with a smooth outside of iron plates, but more often by having an open net-work through which the wind and waves can pass; stability being assured by the disposition of the supports, and the arrangement of the bracing; in this respect the principle followed for a lighthouse being similar to that in an iron landing-pier.

Exposure to wind and wave.

Open framework of iron.

The numerous iron lighthouses that have been built may be divided into three principal types. The first is that of resembling a stone tower by having its full diameter enclosed, this being sometimes adopted because of its supposed more pleasing appearance, or to afford space within for living rooms. It is, however, more expensive than other kinds, and is seldom adopted. The second type is that of a central shaft or column (which for lights of the first 3 orders is about 6 ft. diameter) containing a spiral staircase, and round this central shaft are arranged a series of exterior columns of small diameter strongly attached to the central one at each tier by horizontal bracing, and continuously from top to bottom by diagonal bracing. Towers of this kind have in plan the form of a polygon, the diameter of which ranges from 10 ft. to 15 ft., according to the diameter of the lantern. Towers such as these suitable for lights of the first 3 orders would cost about £700 to £1,000 if made 50 ft. high, and weigh about 40 tons for transport; from £1,100 to £1,300 for a height of 60 ft., with a weight of 50 to 60 tons; from £1,800 to £2,000 for a height of 100 ft., with a weight of about 70 to 100 tons; and about £4,000 for a tower 150 ft. high, with a weight of about 150 tons. But while these prices and weights may approximately represent what is necessary for the respective heights above the ground level, extra expense is incurred if, because of the loose nature of the ground, a wide base is necessary or screw-piles and other iron-work are required below. In such cases the weight and cost of the tower would be increased according to the depth and extent of the foundations. The third type of iron tower is that of a central column with only three outer columns connected occasionally by horizontal bracing to the centre. Such towers cost from 10 to 20 per cent. more than those above described.



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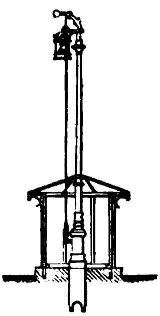
Cost of iron towers.

Extra expense for foundations.

Cost of fixing. The cost of fixing iron towers depends mainly on the difficulties of the site, so that while from £3 to £4 per ton would suffice if erected on the mainland, a wider range is necessary to include what may be the cost on an exposed or isolated site. The approximate prices here stated are for the ironwork only. The woodwork and other **Internal fittings.** internal fittings would cost from £2 to £5 per lineal foot of height in addition. The subsidiary expenses arising from distance, difficulties of access, short hours of working, as well as those often incurred for steamers or boats, all tend to increase the total outlay. Moreover, iron towers as just described are not well suited for residences, only one store and watch-room being generally provided **Dwelling rooms and stores.** immediately below the lantern; living rooms, if provided, greatly increase the cost and are not so comfortable as in a stone tower, and therefore detached sheds or other buildings would, if possible, be necessary or preferable.

The lantern for containing the illuminating apparatus costs about **Cost of lantern.** £750 for a light of the 1st order, about £500 for one of the 2nd order, and about £350 for one of the 3rd order. The cost of the optical and illuminating apparatus depends mainly on the area of illumination (whether all or part only of 360°), but also on the character of the light; and there is therefore a wide range of difference. Thus according to these circumstances an apparatus of the 1st order **Cost of optical apparatus.** may be of any price between £1,500 and £3,000; an apparatus of the 2nd order, £1,000 to £2,000; an apparatus of the 3rd order, £700 to £1,300. To the above prices of lanterns and apparatus it would generally be necessary to add from 5 to 10 per cent. for accessory and duplicate parts.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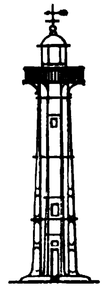
While the foregoing particulars may indicate the cost of lighthouses in simple cases, there are often occasions of great difficulty which are outside any ordinary estimate of cost. Thus, while many important lighthouses have been constructed at a total cost including all accessories of from £60 to £100 per foot of height, other structures on exposed or difficult sites have cost from £150 to £300 per foot, and in a few cases even as much as £500; such an extreme rate arising either from the extraordinary difficulties or from the number and extent of subsidiary charges for land, adaptation of the site, foundations, and buildings.

Harbour-lights. The above prices are for sea-lights only, a much lower rate of expenditure being necessary for harbour-lights. In regard to the opti-



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cal apparatus, whatever may be the intensity of the light, the same principle is applied as in sea-lights, the saving being in the size and number of the prisms and the various accessories of the apparatus. Beginning at the smallest, pillars 20 ft. high with lantern and apparatus of illuminating force equal to that of a steamship light would cost from £50 to £100, rising to £200 for a pillar with a light of the 6th order, and with a cabin for storing the accessories. Stronger columns suitable for lights of the 5th and 6th orders cost, exclusive of the lantern and apparatus, from £100 to £150. Iron towers 20 ft. to 30 ft. high, suitable for lights of the 4th, 5th, and 6th order, with a spiral staircase within and gallery at the top, cost from £300 to £500. The lantern and apparatus for lights of the 4th, 5th, and 6th orders cost from £200 to £500.

Electric light. *See page 96.*

The *Electric Light* has been introduced with great success in several important lighthouses, and its use will probably become greatly extended. In regard to the tower and the lantern, the system usual in ordinary lighthouses is generally followed, and subject to contain modification in the lens apparatus also. The additional apparatus consists of a motor which may be either a steam-engine gas-engine or compressed-air engine, the dynamo-electric machine or generator, and the lamp. But while serviceable for lighthouses situated on shore and within reach of skilled workmen to maintain in working order the more delicate parts of the apparatus, it has not yet (1880) been considered prudent to adopt the electric light for isolated beacons. The cost of the machinery and equipment is increased by the necessity of having all in duplicate. The cost of maintenance is more than for ordinary lamps, but less if reckoned according to the brilliancy of the light.

Lightships.

Lightships are generally used as warnings against shoals, in situations where lighthouses would be impossible or too costly for the purpose in view. The expenses connected with the establishment of lightships round the British coast have varied considerably, but they have cost on an average about £5,000 each.

Illuminated buoys. *See* GAS, *page 293.*

Buoys for marking navigable channels can be made as serviceable by night as by day by charging them with compressed gas of a special kind, which, as it issues forth, burns in a suitable apparatus, and cannot be extinguished by the waves. Such buoys of wrought-

iron or steel, of capacity sufficient for six weeks' illumination (burning night and day) cost from £300 to £500 each exclusive of moorings. The shore apparatus for making and compressing the gas costs from £500 to £1,000, to which would probably have to be added £500 for storage-tanks and buildings. One set of apparatus and buildings would serve for numerous buoys.

See page 446.

Particulars on which lighthouse design is based.

The following are the particulars upon which the design of a lighthouse and its cost depend, and which must be furnished to the engineer. In important cases, where difficulties of site have to be considered, even the fullest information will allow only of a preliminary scheme, a careful survey by the engineer who is to make the design being then necessary.

Purpose.

1. The general purpose of the light, whether as a sea-light or only as a local harbour-light.

Area to be illumined.

2. A chart showing the whole area within range of the proposed light and the neighbouring coast-line, indicating the headlands or rocks which would hide a view of the light. Upon this chart should be marked the soundings, the routes generally taken by passing and approaching vessels, the existing buoys or landmarks and the rocks, shoals, currents, or other dangers to be avoided, and which it is the purpose of the light to warn against. The site on which it is proposed to erect the lighthouse, or alternative sites, should be marked, and the reasons for and against each stated. Upon the chart, or on a map of smaller scale, the other lights in the vicinity should be marked with the area they each illumine, the character of each, and the course generally adopted by vessels in passing from one to the other and making land.

Position of the lights.

Site.

3. A plan on a large scale of the site on which it is proposed to erect the lighthouse with the levels above the sea marked on it. If on shore, with no difficulties, a general description of the ground, the area available for buildings, and its suitability for foundations will suffice. If on a shoal or rock or reef, the fullest possible information should be given, not only of its present condition, but of any alteration which may have been noticed in the past so far as will tell the probabilities for the future. If sand or mud, its density and firmness and the underlying strata as ascertained by trial borings; also its liability to shift under the action of the sea. If the foundations be very bad, the suitability of the sea-bed as anchorage for floating lightships or illuminated buoys. If the site be rock, its nature and strati-

Foundations.

See page 386.

fication, with a description of any fissures or hollows by which its solidity and permanency may be estimated. These latter particulars may with advantage be given on a relief map or model, showing the contour of the site and the level of the sea at various seasons. If the site is covered at any time by water, or washed by the waves, the periods at which work could be carried on, and the facilities for landing and erecting temporary buildings should be described as far as possible.

Contour of rocks.

4. If the lighthouse or its foundation is to be actually exposed to the waves, particulars should be furnished as to their direction, height, and force; the strength of the wind, the directions from which it blows oftenest and strongest, and the occurrence of hurricanes. The climate should be described, the extremes of heat and cold, the rainfall and snowfall. If fogs or mist occur in the neighbourhood, or within the range of the proposed lighthouse, their seasons, duration, and height, and any circumstances which may assist in determining the power and range of the light, and the necessity for foghorns or bells.

Force and direction of wind and wave.

Climate.

Fogs.

5. If the site of the proposed lighthouse is only accessible by boats, the frequency with which it can be visited, the size and kind of vessels obtainable, the likelihood of inaccessibility during rough weather, and the distance from which food, fuel, water, and stores would have to be brought, and any other circumstance by which the accommodation for living room and stores may be considered.

Accessibility of site.

6. If the site be on shore, the nature of the water supply, so far as will indicate the necessity for tanks, wells, or pumps. If illuminating gas is available, or coal for gas making, its kind and cost should be stated.

Water supply.

Gas.

7. The kind of stone, brick, lime, timber, and other building materials available, and their approximate cost; the distance they would have to be brought, the distance from a port of arrival, the cost of carriage, and the dues and import taxes which would have to be paid. The kind of skilled workmen and labourers obtainable and their rates of wages, so far as will determine the kind and number of workmen who would have to be sent to erect the lighthouse.

Building materials.

Workmen.

8. The tenure on which the site would be held, the funds avail able for construction and maintenance, and their source; the authority or jurisdiction under whom the lighthouse would be built and managed.

Tenure.

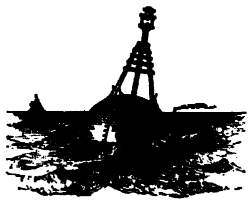
Jurisdiction.

Cost of maintenance.

Tolls.

Lighthouses are in almost all countries built at the cost of the State, and are maintained free of special charge to shipowners or mariners. England is one of the few countries where the cost of maintenance is met by tolls on passing vessels. There have also been occasional cases where concessions have been granted to private speculators who have been allowed to reap a revenue from tolls and imposts. Harbour-lights are generally constructed at the cost of the port authorities, who either maintain them free, or include the charge in general harbour dues.

THE END.



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